Specification of Narrow Band ISDB-T

29 NOVEMBER 1999

Contents

Foreword

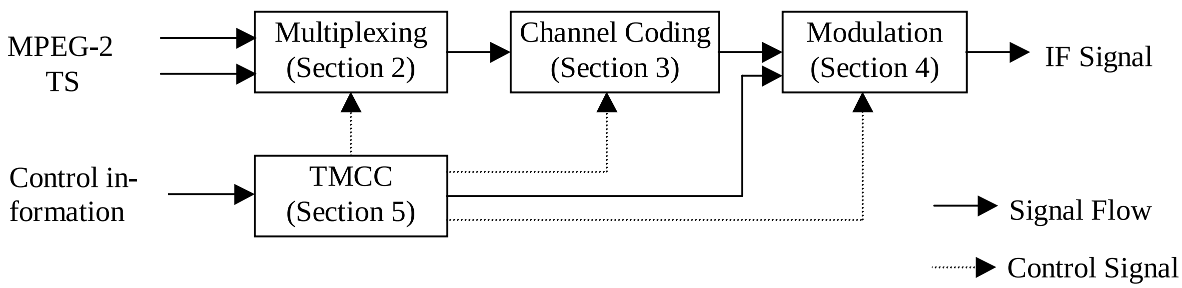
The system specification for digital terrestrial sound broadcasting has been produced by the Association of Radio Industries and Businesses (ARIB) in October 1999, and has been reported as the Japan Standard to the Telecommunication Technology Council of Ministry of Posts and Telecommunications (MPT) in November 1999.

1 Overview

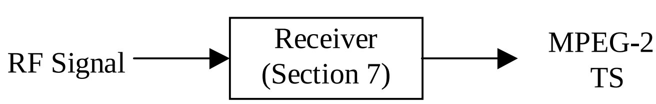
The specification describes baseline transmission system of the narrow-band Terrestrial Integrated Services Digital Broadcasting (ISDB-T). The system can transmit various kinds of digital contents including audio programs and various kinds of data programs.

1.1 Scope

The specification specifies the transmission system which delivers IF signal with input signals of MPEG-2 transport streams, which includes the re-multiplex, channel coding, modulation, transmission control and the corresponding functions of the receiver as shown in the functional block diagrams in Fig.1-1.



(a) Diagram of transmitter



(b) Diagram of receiver

Fig. 1-1 Functional block diagrams

1.2 Baseline of narrow-band ISDB-T

By using MPEG-2 audio coding and MPEG-2 systems in a multiplexing process, narrow-band ISDB-T provides common elements in operation and reception among wide-band ISDB-T, digital satellite broadcasting.

Transport Streams are formed into data groups (Data Segments) prior to channel coding. Channel coding is carried out to each hierarchical layer. After channel coding, data segments are formed into single or three OFDM segments together with pilot signals (See Fig.1-2). A bandwidth of OFDM segment is a fourteenth of television channel bandwidth (6,7 or 8 MHz). Hereinafter, a case of about 429 kHz (6/14MHz) is described as an example.

1.3 Hierarchical transmission and partial reception

Hierarchical transmission of narrow-band ISDB-T is achieved only in the case of three-segment transmission. There are only two layers of A and B. The hierarchical layer parameters are carrier modulation scheme, coding rates of the inner coder, and length of the time interleaving.

The centre segment of three-segment transmission should be able to be received by 1-segment receiver for compatibility between receivers. Owing to the common structure of OFDM segment, 1-segment receiver can partially receive a centre segment of wide-band ISDB-T signal whenever an independent program is transmitted in the centre segment.

Fig. 1-1 shows an example of hierarchical transmission and partial reception.

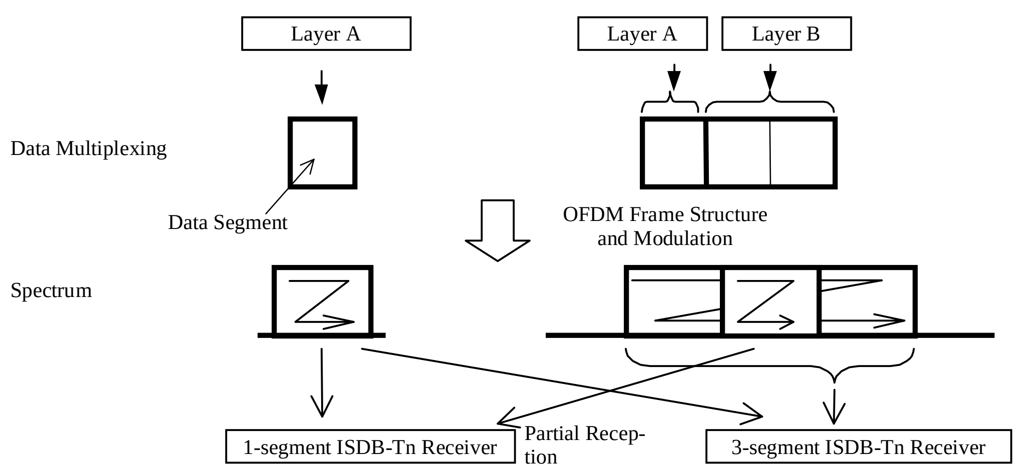


Fig. 1-2 Example diagram of hierarchical transmission and partial reception

1.3 Transmission parameters

The transmission parameters for the 1-segment format and the 3-segment format are shown in table 1-1 and 1-2. The transmission capacities of the 1-segment and the 3-segment are shown in table 1-3 and 1-4 respectively.

Table 1-1 Transmission parameters for the 1-segment transmission

Mode		Mode 1	Mode 2	Mode 3
Segment Bandwidth		6000/14 = 428.57… kHz		
Bandwidth		6000/14(kHz) + 250/63(kHz) = 432.5...kHz	6000/14(kHz) + 125/63(kHz) = 430.5...kHz	6000/14(kHz) + 125/126(kHz) = 429.5...kHz
Number of Segments for Differential Modulation		n_d		
Number of Segments for Coherent Modulation		n_s ($n_s+n_d=1$)		
Carrier Spacing		250/63 = 3.968…kHz	125/63 = 1.984…kHz	125/126 = 0.992…kHz
Number of Carriers	Total	108 + 1 = 109	216 + 1 = 217	432 + 1 = 433
	Data	96	192	384
	SP*1	$9\times n_s$	$18\times n_s$	$36\times n_s$
	CP*1	$n_d + 1$	$n_d + 1$	$n_d + 1$
	TMCC*2	$n_s + 5\times n_d$	$2\times n_s + 10\times n_d$	$4\times n_s + 20\times n_d$
	AC1*3	2	4	8
	AC2*3	$4\times n_d$	$9\times n_d$	$19\times n_d$
Carrier Modulation		QPSK, 16QAM, 64QAM, DQPSK		
Number of Symbol per Frame		204		
Effective Symbol Duration		252 μs	504 μs	1.008 ms
Guard Interval		63 μs (1/4), 31.5 μs (1/8), 15.75 μs (1/16), 7.875 μs (1/32)	126 μs (1/4), 63 μs (1/8), 31.5 μs (1/16), 15.75 μs (1/32)	252 μs (1/4), 126 μs (1/8), 63 μs (1/16), 31.5 μs (1/32)
Frame Duration		64.26 ms (1/4), 57.834 ms (1/8), 54.621 ms (1/16), 53.0145 ms (1/32)	128.52 ms (1/4), 115.668 ms (1/8), 109.242 ms (1/16), 106.029 ms (1/32)	257.04 ms (1/4), 231.336 ms (1/8), 218.464 ms (1/16), 212.058 ms (1/32)
FFT sample clock		64/63 = 1.0158… MHz		
Inner Code		Convolutional Code (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer Code		RS (204,188)		

*1: SP (Scattered Pilot), and CP (Continual Pilot) can be used for frequency synchronization and channel estimation.

The number of CP includes CPs on all segments and a CP for higher edge of whole bandwidth.

*2: TMCC (Transmission and Multiplexing Configuration Control) carries information on transmission parameters.

*3: AC (Auxiliary Channel) carries ancillary information for network operation.

Table 1-2 Transmission parameters for the 3-segment transmission

Mode		Mode 1	Mode 2	Mode 3
Segment Bandwidth		6000/14 = 428.57… kHz		
Bandwidth		6000/14(kHz)×3 + 250/63(kHz) = 1.289…MHz	6000/14(kHz)×3 + 125/63(kHz) = 1.287…MHz	6000/14(kHz)×3 + 125/126(kHz) = 1.286…MHz
Number of Segments for Differential Modulation		n_d		
Number of Segments for Coherent Modulation		n_s (n_s+n_d=3)		
Carrier Spacing		250/63 = 3.968…kHz	125/63 = 1.984…kHz	125/126 = 0.992…kHz
Number of Carriers	Total	108×3 + 1 = 325	216×3 + 1 = 649	432×3 + 1 = 1297
	Data	96×3 = 288	192×3 = 576	384×3 = 1152
	SP	$9\times n_s$	$18\times n_s$	$36\times n_s$
	CP	$n_d + 1$	$n_d + 1$	$n_d + 1$
	TMCC	$n_s + 5\times n_d$	$2\times n_s + 10\times n_d$	$4\times n_s + 20\times n_d$
	AC1	2×3 = 6	4×3 = 12	8×3 = 24
	AC2	$4\times n_d$	$9\times n_d$	$19\times n_d$
Carrier Modulation		QPSK, 16QAM, 64QAM, DQPSK		
Number of Symbol per Frame		204		
Effective Symbol Duration		252 µs	504 µs	1.008 ms
Guard Interval		63 µs (1/4), 31.5 µs (1/8), 15.75 µs (1/16), 7.875 µs (1/32)	126 µs (1/4), 63 µs (1/8), 31.5 µs (1/16), 15.75 µs (1/32)	252 µs (1/4), 126 µs (1/8), 63 µs (1/16), 31.5 µs (1/32)
Frame Duration		64.26 ms (1/4), 57.834 ms (1/8), 54.621 ms (1/16), 53.0145 ms (1/32)	128.52 ms (1/4), 115.668 ms (1/8), 109.242 ms (1/16), 106.029 ms (1/32)	257.04 ms (1/4), 231.336 ms (1/8), 218.464 ms (1/16), 212.058 ms (1/32)
FFT sample clock		128/63 = 2.0317… MHz		
Inner Code		Convolutional Code (1/2, 2/3, 3/4, 5/6, 7/8)		
Outer Code		RS (204,188)		

Table 1-3 Information bit-rates for the 1-segment transmission

Carrier Modulation	Convolutional Code	Number of Transmitting TSPs*1 (Mode 1 / 2 / 3)	Information Rates (kbps) Guard Interval Ratio 1/4	Guard Interval Ratio 1/8	Guard Interval Ratio 1/16	Guard Interval Ratio 1/32
DQPSK QPSK	1/2	12/ 24 / 48	280.85	312.06	330.42	340.43
	2/3	16/ 32 / 64	374.47	416.08	440.56	453.91
	3/4	18/ 36 / 72	421.28	468.09	495.63	510.65
	5/6	20/ 40 / 80	468.09	520.10	550.70	567.39
	7/8	21/ 42 / 84	491.50	546.11	578.23	595.76
16QAM	1/2	24/ 48 / 96	561.71	624.13	660.84	680.87
	2/3	32/ 64 / 128	748.95	832.17	881.12	907.82
	3/4	36/ 72 / 144	842.57	936.19	991.26	1021.30
	5/6	40/ 80 / 160	936.19	1040.21	1101.40	1134.78
	7/8	42/ 84 / 168	983.00	1092.22	1156.47	1191.52
64QAM	1/2	36/ 72 / 144	842.57	936.19	991.26	1021.30
	2/3	48/ 96 / 192	1123.43	1248.26	1321.68	1361.74
	3/4	54/ 108 / 216	1263.86	1404.29	1486.90	1531.95
	5/6	60/ 120 / 240	1404.29	1560.32	1652.11	1702.17
	7/8	63/ 126 / 252	1474.50	1638.34	1734.71	1787.28

*1: The number of Transmitting TSPs per one OFDM frame.

Table 1-4 Information bit-rates for the 3-segments Format*1

Carrier Modula-tion	Convolu-tional Code	Number of Transmitting TSPs*1 (Mode 1 / 2 / 3)	Information Rates (kbps) Guard Interval Ratio 1/4	Guard Interval Ratio 1/8	Guard Interval Ratio 1/16	Guard Interval Ratio 1/32
DQPSK QPSK	1/2	12/ 24 / 48	0.842	0.936	0.991	1.021
	2/3	16/ 32 / 64	1.123	1.248	1.321	1.361
	3/4	18/ 36 / 72	1.263	1.404	1.486	1.531
	5/6	20/ 40 / 80	1.404	1.560	1.652	1.702
	7/8	21/ 42 / 84	1.474	1.638	1.734	1.787
16QAM	1/2	24/ 48 / 96	1.685	1.872	1.982	2.042
	2/3	32/ 64 / 128	2.246	2.496	2.643	2.723
	3/4	36/ 72 / 144	2.527	2.808	2.973	3.063
	5/6	40/ 80 / 160	2.808	3.120	3.304	3.404
	7/8	42/ 84 / 168	2.949	3.276	3.469	3.574
64QAM	1/2	36/ 72 / 144	2.527	2.808	2.973	3.063
	2/3	48/ 96 / 192	3.370	3.744	3.965	4.085
	3/4	54/ 108 / 216	3.791	4.212	4.460	4.595
	5/6	60/ 120 / 240	4.212	4.680	4.956	5.106
	7/8	63/ 126 / 252	4.423	4.915	5.204	5.361

*1: In the case of the 3-segments scheme, information rate can be calculated by the combination of segment information rates.

2. Multiplex

The multiplex of the system is compatible with MPEG-2 Transport Stream (TS) ISO/IEC 13813[1]. In addition, Multiplex Frame and TMCC descriptors are defined for hierarchical transmission with a single TS.

2.1 Multiplex Frame

To achieve hierarchical transmission using the Band Segmented Transmission OFDM scheme, the ISDB-T system defines a multiplex frame of TS within the scope of MPEG-2. In the multiplex frame, TS is a continual stream of 204-byte RS-TSP composed of TSP and null data of 16 bytes or Reed-Solomon parity.

The duration of the multiplex frame is adjusted to that of the OFDM frame by counting RS-TSPs using a clock that is two times faster than the 1.0158... MHz used for IFFT sampling in the case of 1-segment scheme. In the case of the 3-segment scheme the duration of the multiples frame is adjusted to that of the OFDM frame by counting RS-TSPs using a clock that is four times faster than 2.0317... MHz.

The number of transmission-TSPs actually transmitted in one OFDM frame is shown in table 1-3. The number is smaller than the corresponding number of RS-TSP on the multiplex frame shown in table 2-1. The difference in number of TSPs between the two numbers corresponds to the number of inserted null RS-TSPs.

The method of re-multiplexing a TS for the multiplex frame is predetermined in such a way that the receiver regenerates the same TS (see section 7.2).

An example of TS in the multiplex frame is shown in Fig. 2-1. RS-TSPs in the multiplex frame belong to layer-A, B. Null RS-TSPs are not transmitted.

Table 2-1 Number of interfaced TSP of Multiplexing Frame

Mode		Number of TSPs per one Multiplexing Frame			
		Guard Interval Ratio 1/4	Guard Interval Ratio 1/8	Guard Interval Ratio 1/16	Guard Interval Ratio 1/32
1-segment Format	Mode 1	80	72	68	66
	Mode 2	160	144	136	132
	Mode 3	320	288	272	254
3-segment Format	Mode 1	320	288	272	254
	Mode 2	640	576	544	528
	Mode 3	1280	1152	1088	1056

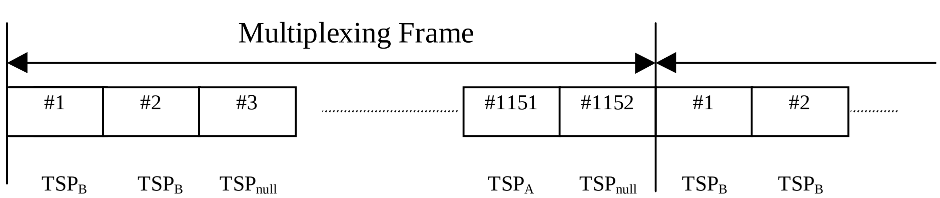


Fig. 2-1 An Example of Transport Stream

(Mode 1, Guard interval ratio 1/8)

2.2 Application of MPEG-2 control signals

For the hierarchical transmission, the next application rules are introduced.

2.2.1 Multiplex of PAT, NIT and CAT

The multiplex of PAT, NIT and CAT obeys the rule that:

- these signals shall be transmitted in the most robust transmission layer or;
- these signals shall be duplicated and transmitted in the most robust transmission layer and the partial reception layer in the case the partial reception layer is not the most robust transmission layer

2.2.2 Multiplex of PMT

The PMT shall be transmitted in the most robust transmission layer.

2.2.3 Multiplex of PCR-packet for Partial Reception layer

The multiplex of the PCR packet shall obey the rule that:

- one PCR packet per multiplex frame is transmitted periodically (for Mode 1) or;
- two PCR packets with same interval as that of Mode 1 are transmitted every multiplex frame (for Mode 2) or;
- four PCR packets with same interval as that of Mode 1 are transmitted every multiplex frame (for Mode 3).

3. Channel coding

This section describes the channel-coding block, which receives the packets arranged in the multiplex frame and delivers the channel-coded packets to the OFDM modulation block.

3.1 Functional block diagram of channel coding

Fig. 3-1 shows the functional block diagram of channel coding of narrow-band ISDB-T.

The duration of the multiplex frame coincides with the OFDM frame by counting the bytes in the multiplex frame using a faster clock than IFFT-sampling rate described previous section.

At the interface between the multiplex block and the outer coding block, the head byte of the multiplex frame (corresponding to the sync.-byte of TSP) is regarded as the head byte of OFDM frame. In bit-wise description, the MSB of the head byte is regarded as the synchronisation bit of OFDM frame.

For the 3-segment transmission, RS-TSP stream is divided to two layers in accordance with the transmission-control information. In each layer, carrier-modulation scheme, error correction, and time-interleaving length can be specified independently. The information on these parameters is transmitted using Transmission and Multiplexing Configuration Control (TMCC) carriers.

After channel coding, data are framed into OFDM-transmission frame along with pilot signal, TMCC signal, and Auxiliary channel signal.

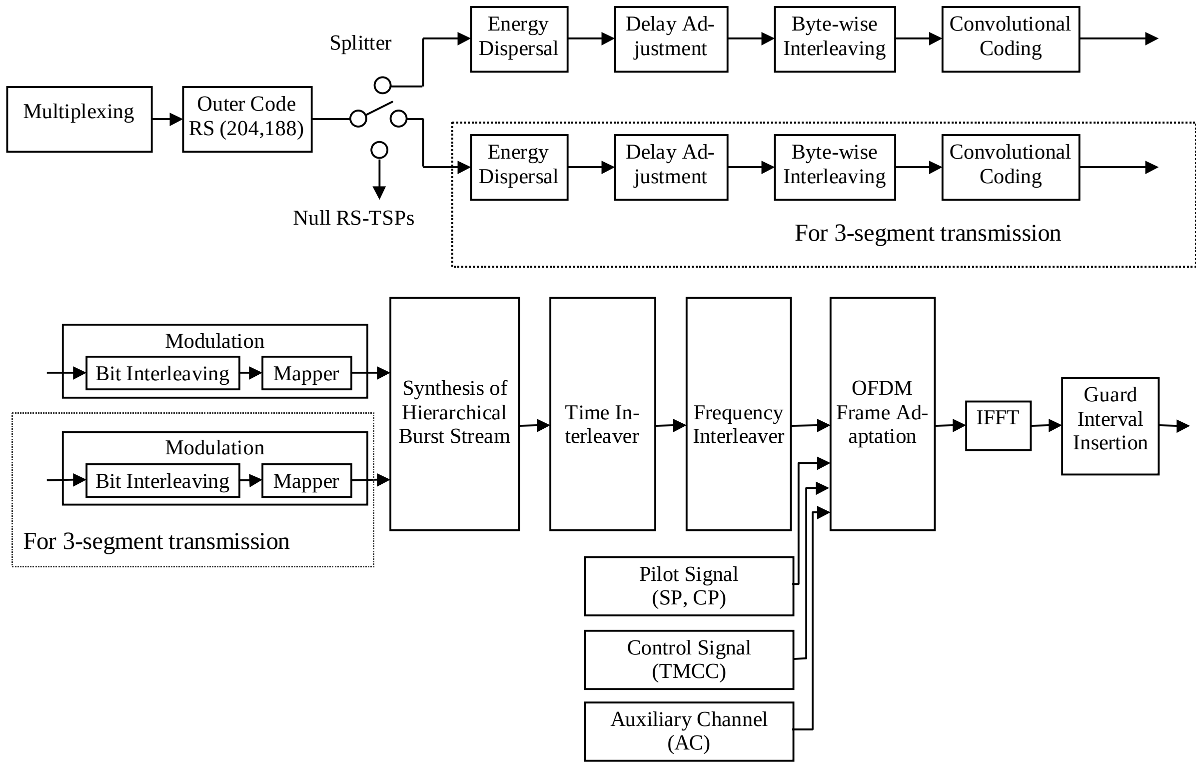


Fig. 3-1 Channel coding diagram

3.2 Outer coding

Reed-Solomon RS (204,188,t=8) shortened code is applied to each MPEG-2 TSP (see Fig. 2-3(a)) to generate an error protected TSP (see Fig. 2-3(b)). Reed-Solomon code can correct up to 8 random erroneous bytes in a received 204-byte word.

Field Generator Polynomial: $p(x)= x^8+x^4+x^3+x^2+1$

Code Generator Polynomial: $g(x)=(x-\lambda^0)(x-\lambda^1)(x-\lambda^2)(x-\lambda^3)\cdots(x-\lambda^{15})$

where, $\lambda=02_{HEX}$

It should be noted that null TSPs from the multiplexer are also coded to RS (204, 188) packets.

MPEG-2 TSP and RS error protected TSP are shown in Fig. 2-3. RS error protected TSP is called transmission TSP.

Sync. 1 byte	MPEG-2 transport MUX data 187 bytes

(a) MPEG-2 Transport Stream Packet (TSP)

Sync. 1 byte	MPEG-2 transport MUX data 187 bytes	16 Parity bytes

(b) Transmission TSP, RS (204,188) error protected TSP

Fig. 3-2 MPEG-2 TSP and Transmission TSP

3.3 Division of TS

A TS from the outer encoder shall be divided every 204 bytes, and then sorted into up to three pre-determined layers in accordance with hierarchical control information. In this process, each TSP is divided at the end of the synchronization byte and the SYNC of OFDM frame is delayed by a byte. In the case of non-hierarchical transmission, one certain stream should only be defined as the stream for the whole transmission.

It should be noted that null TSPs in the multiplex frame are removed at the splitter.

Fig. 3-3 shows division of TS and shift of OFDM frame SYNC.

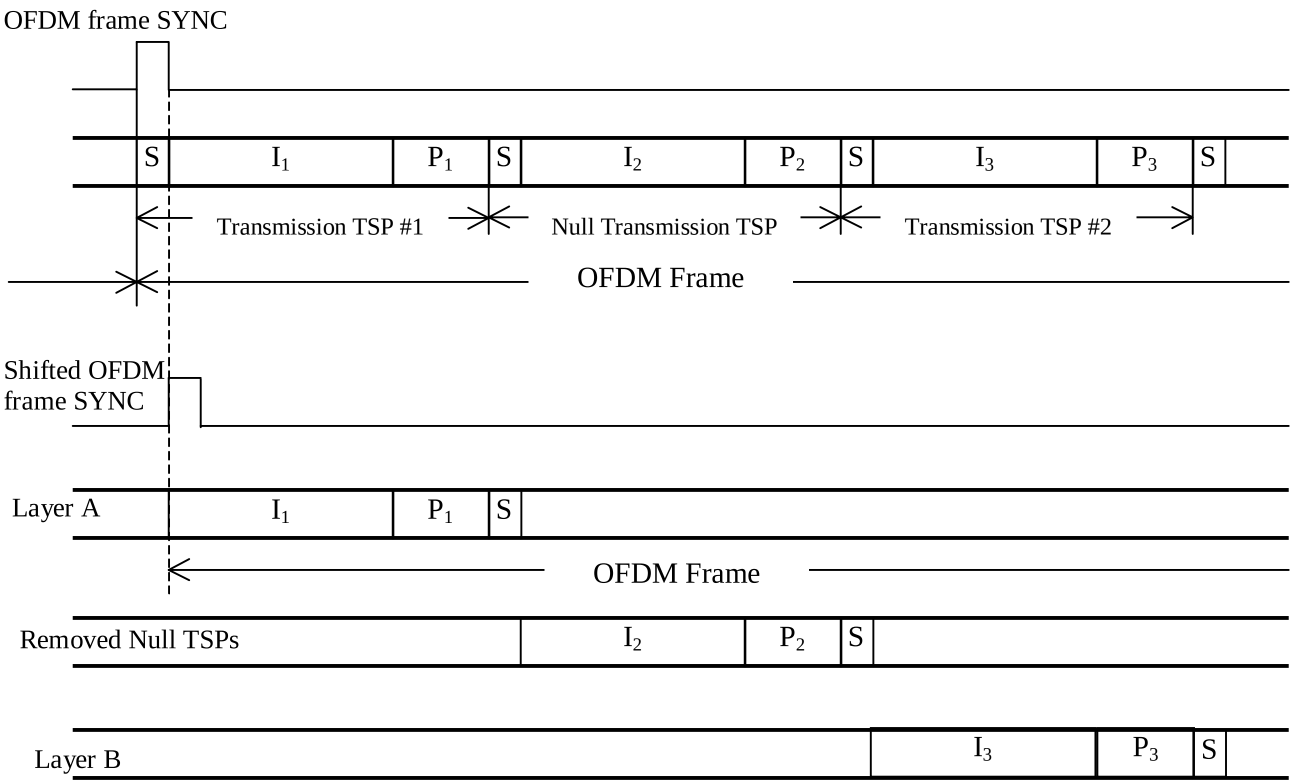


Fig. 3-3 Dividing process of TS

3.4 Energy dispersal

In order to ensure adequate binary transitions, the data from the splitter is randomized with PRBS sequence generated according to Fig. 2-5.

The polynomial for the pseudo random binary sequence (PRBS) generator shall be:

$$g(x) = x^{15} + x^{14} + 1$$

Loading of the sequence '100101010000000' into the PRBS registers is initiated at the start of every OFDM frame.

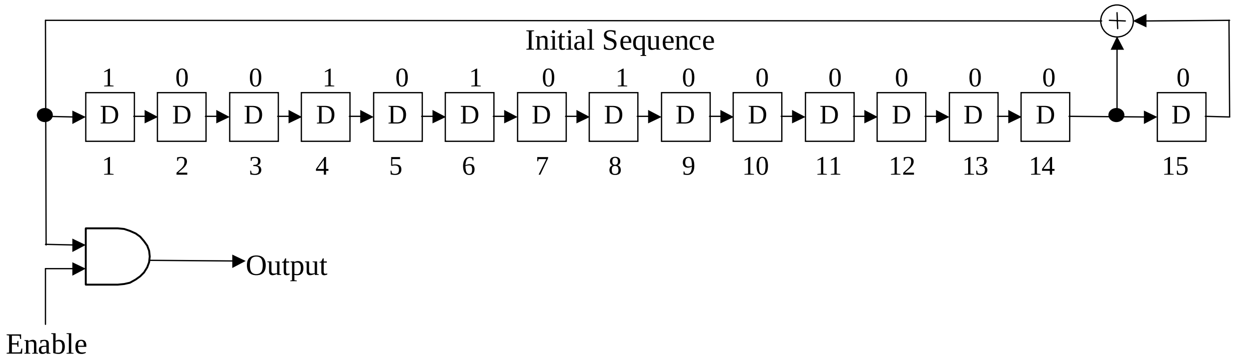


Fig. 3-4 PRBS generation diagram

3.5 Delay adjustment

In the byte-wise interleaving, the delay caused in the interleaving process differs from stream to stream of different layer depending on its properties (i.e. modulation and channel coding). In order to compensate for the delay difference including de-interleaving in the receiver, the delay adjustment is carried out prior to the byte-wise interleaving on the transmission side.

The amount of delay to be adjusted for is defined in terms of the number of TSPs for each layer stream, as shown in table 2-2.

In each layer, the total delay including 11 TSPs of the byte-wise interleaving and de-interleaving processes itself is adjusted to one multiplex frame independently of its hierarchical properties.

In table 2-2, N indicates the number of segments used for a certain layer. In the case of the 1-segment transmission N equals 1, and in the case of the 3-segments N equals 1 or 2.

Table 3-1 Delay adjustment for byte interleaving

Carrier	Convolutional code rate	Number of Transmission TSPs for Delay Adjustment		
		Mode 1	Mode 2	Mode 3
DQPSK QPSK	1/2	12×N-11	24×N-11	48×N-11
	2/3	16×N-11	32×N-11	64×N-11
	3/4	18×N-11	36×N-11	72×N-11
	5/6	20×N-11	40×N-11	80×N-11
	7/8	21×N-11	42×N-11	84×N-11
16QAM	1/2	24×N-11	48×N-11	96×N-11
	2/3	32×N-11	62×N-11	128×N-11
	3/4	36×N-11	72×N-11	144×N-11
	5/6	40×N-11	80×N-11	160×N-11
	7/8	42×N-11	84×N-11	168×N-11
64QAM	1/2	36×N-11	72×N-11	144×N-11
	2/3	48×N-11	92×N-11	192×N-11
	3/4	54×N-11	108×N-11	216×N-11
	5/6	60×N-11	120×N-11	240×N-11
	7/8	63×N-11	126×N-11	252×N-11

N: the number of segments used in the layer

3.6 Byte-wise interleaving (Inter-code interleaving)

Following the conceptual scheme of Fig. 2-6, convolutional byte-wise interleaving with length of I = 12 is applied to the 204-byte error protected and randomised packets. It should be noted that for synchronisation purposes, the bytes just after the SYNC bytes shall always be routed in branch ‘0’ of the interleaver (corresponding to a null delay).

The interleaver may be composed of I = 12 branches, cyclically connected to the input byte-stream by the input switch. Each branch j shall be a First-in First-out (FIFO) shift register, with length of j $\times$ 17 bytes. The cells of the FIFO shall contain 1 byte, and the input and output switches shall be synchronised.

The de-interleaver is similar in principle, to the interleaver, but the branch indices are reversed. Total delay caused by interleaver and de-interleaver is 17 $\times$ 11 $\times$ 12 bytes (corresponding to 11 TSPs).

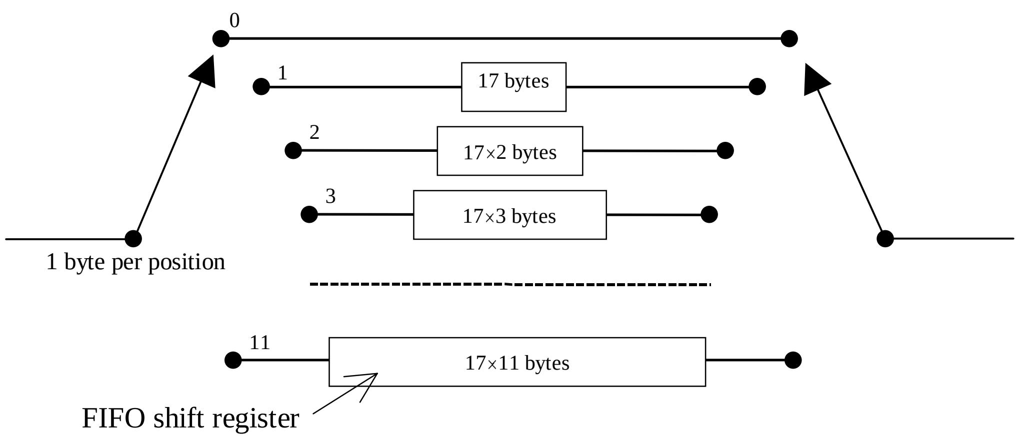


Fig. 3-5 Conceptual diagram of the outer interleaver

3.7 Inner coding (Convolutional codes)

The system shall allow for a range of punctured convolutional codes, based on a mother convolutional code of rate 1/2 with 64 states. This will allow selection of the most appropriate property of error correction for a given service or data rate in the ISDB-T including mobile services. The generator polynomials of the mother code are $G_1 = 171_{OCT}$ for X output and $G_2 = 133_{OCT}$ for Y output.

The inner encoder, having constraint length k=7 and mother convolutional code rate of 1/2, is shown in Fig. 2-7. The punctured patterns and transmitted sequences are given in table 2-3.

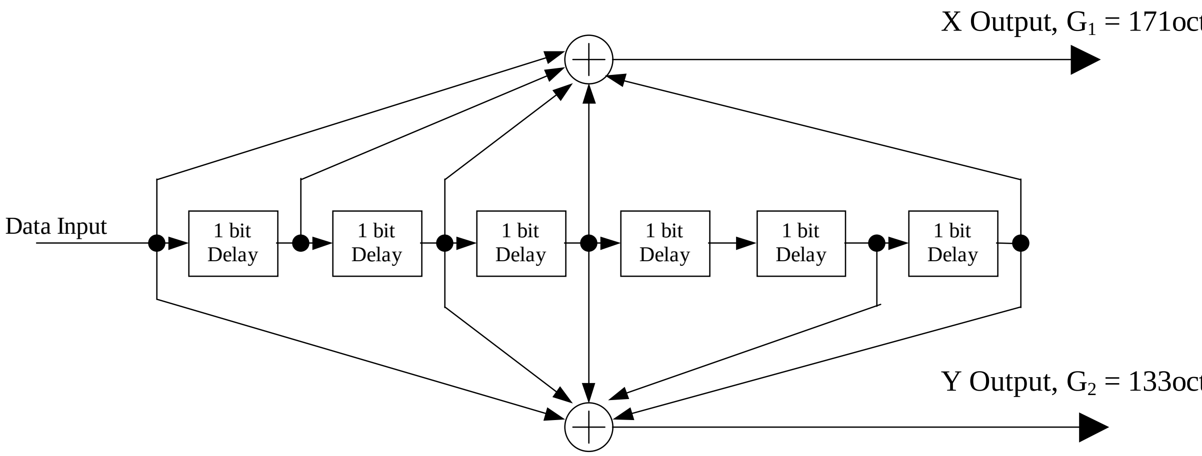


Fig. 3-6 Mother convolutional code of coding rate of 1/2 (Constraint Length = 7)

Table 3-2 Puncturing pattern and transmitting sequence

Code Rates	Puncturing Pattern	Transmitted Sequence
1/2	X : 1 Y : 1	X_1, Y_1
2/3	X : 1 0 Y : 1 1	X_1, Y_1, Y_2
3/4	X : 1 0 1 Y : 1 1 0	X_1, Y_1, Y_2, X_3
5/6	X : 1 0 1 0 1 Y : 1 1 0 1 0	X_1, Y_1, Y_2, X_3 Y_4, X_5
7/8	X : 1 0 0 0 1 0 1 Y : 1 1 1 1 0 1 0	X_1, Y_1, Y_2, Y_3, Y_4, X_5, Y_6, X_7

4. Modulation

Configuration of modulation block is shown in Fig. 2-8. After bit-wise interleaving, data of each layer mapped to the complex domain.

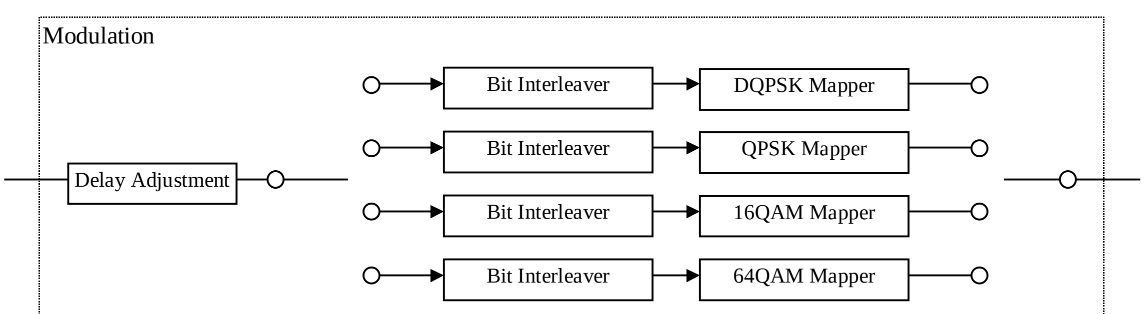


Fig. 4-1 Configuration of modulation block

4.1 Delay adjustment for bit interleave

Bit interleave causes the delay of 120 complex data (I + jQ) as described in the next section. By adding proper delay shown in table 2-4, total delay in transmitter and receiver is adjusted to the amount of two OFDM symbols.

In table 2-2, N indicates the number of segments used for a certain layer. In the case of the 1-segment transmission N equals 1, and in the case of the 3-segments N equals 1 or 2.

Table 4-1 Delay adjustment for bit interleaving

Modulation	Number of bits for Delay Adjustment		
	Mode 1	Mode 2	Mode 3
DQPSK QPSK	384×N-240	768×N-240	1536×N-240
16QAM	768×N-480	1536×N-480	3072×N-480
64QAM	1152×N-720	2304×N-720	4608×N-720

Where, N indicates the number of segments used in a certain layer.

4.2 Bit interleaving and mapping

4.2.1 DQPSK

The serial bit-sequence at the output of the inner coder is converted into a 2-bit parallel sequence to undergo π/4-shift DQPSK mapping, by which n bits of I-axis and Q-axis data are delivered. The number n may depend on the hardware implementation. After the serial-to-parallel (S/P) conversion, bit-interleaving is carried out by inserting a 120-bit delay on the second output of the S/P converter (see Fig.4-2). Fig. 4-2 shows a block diagram of π/4-shift DQPSK modulation, and Fig. 2-10 hows its constellation.

It should be noted that the 'Delay' in Fig. 4-2 is the delay corresponding to the amount of all the data, which are dealt with during one OFDM symbol period in the data segments dedicated π/4-shift DQPSK mapping. When data segments of N_{s1} are used for the mapping, the delay amounts to $96N_{s1}$ symbols (i.e. $96N_{s1} \times 2$ bits) for Mode 1, $192N_{s1}$ symbols (i.e. $192N_{s1} \times 2$ bits) for Mode 2, and $384N_{s1}$ symbols (i.e. $384N_{s1} \times 2$ bits) for Mode 3.

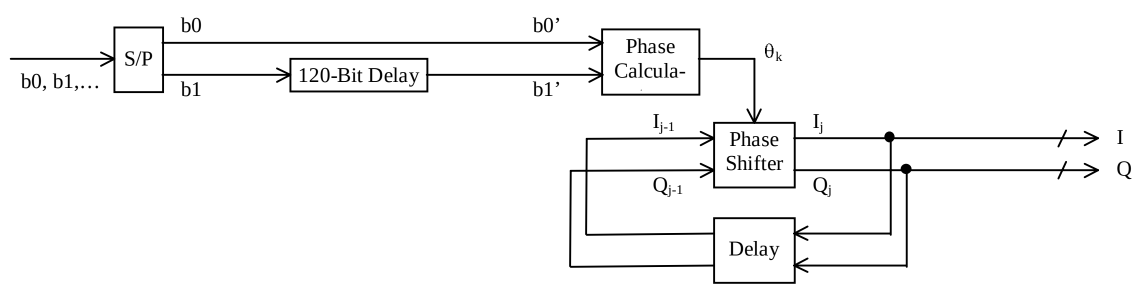


Fig. 4-2 π/4-Shift DQPSK modulation

Input b0’, b1’	Output θ_j
0, 0	$\pi/4$
0, 1	$-\pi/4$
1, 0	$3\pi/4$
1, 1	$-3\pi/4$

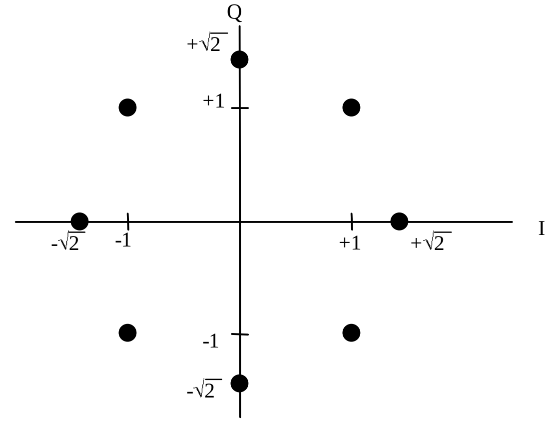


Fig. 4-3 Phase calculation and mapping for π/4-shift DQPSK

Phase shift of complex data is as follows.

$$\begin{pmatrix} I_j \\ Q_j \end{pmatrix} = \begin{pmatrix} \cos\theta_j & -\sin\theta_j \\ \sin\theta_j & \cos\theta_j \end{pmatrix} \begin{pmatrix} I_{j-1} \\ Q_{j-1} \end{pmatrix}$$

Where, (I_j, Q_j) denotes a complex data of j-th symbol, and (I_{j-1},Q_{j-1}) denotes the data one OFDM symbol before.

4.2.2 QPSK

The serial bit sequence at the output of the inner coder is converted into a 2-bit parallel sequence in order to undergo QPSK mapping, by which I-axis and Q-axis data of n bits each are delivered. After the S/P conversion, bit interleaving is carried out by inserting 120-bit delay on the second output of the S/P converter as shown in Fig.4-4. Fig. 4-5 shows the constellation.

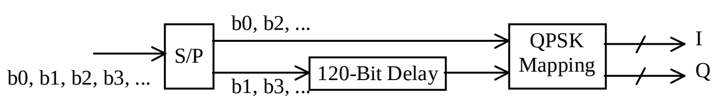


Fig. 4-4 QPSK modulation

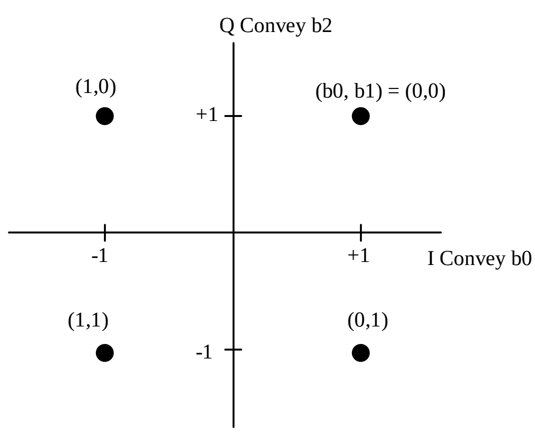


Fig. 4-5 QPSK mapping

4.2.3 16-QAM

The serial bit sequence at the output of the inner coder is converted into a 4-bit parallel sequence in order to undergo 16-QAM mapping, by which n bits of I-axis and Q-axis data are delivered. After S/P conversion, bit interleaving is carried out by bit delays inserted on the b1 to b3 outputs of the S/P converter as shown in Fig. 2-13. Fig. 2-14 shows the constellation.

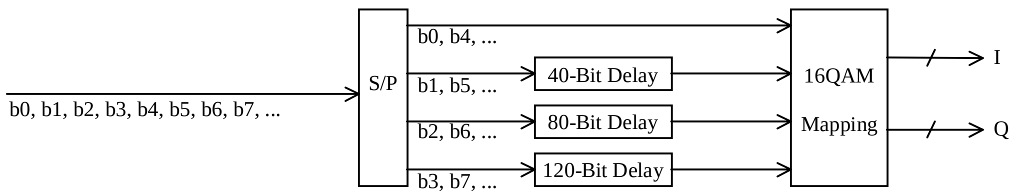


Fig. 4-6 16QAM modulation

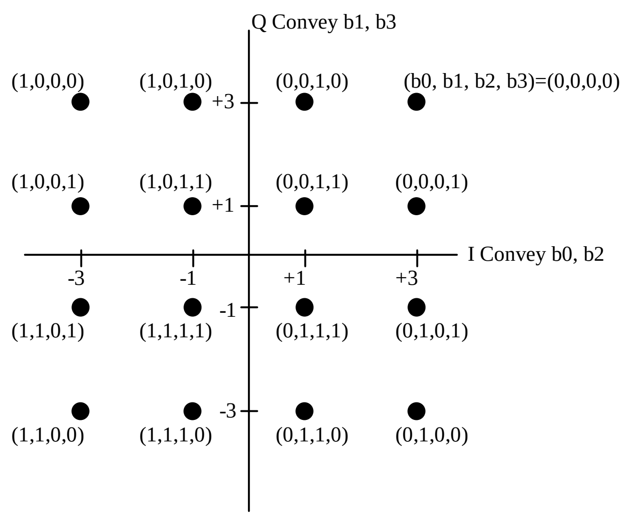


Fig. 4-7 16-QAM mapping

4.2.4 64-QAM

The serial bit sequence at the output of the inner coder is converted into a 6-bit parallel sequence in order to undergo 64-QAM mapping, by which n bits of I-axis and Q-axis data are delivered. After the S/P conversion, bit interleaving is carried out by bit delays inserted on the b1 to b5 outputs of the S/P converter as shown in Fig. 4-8. Fig.4-9 shows the constellation.

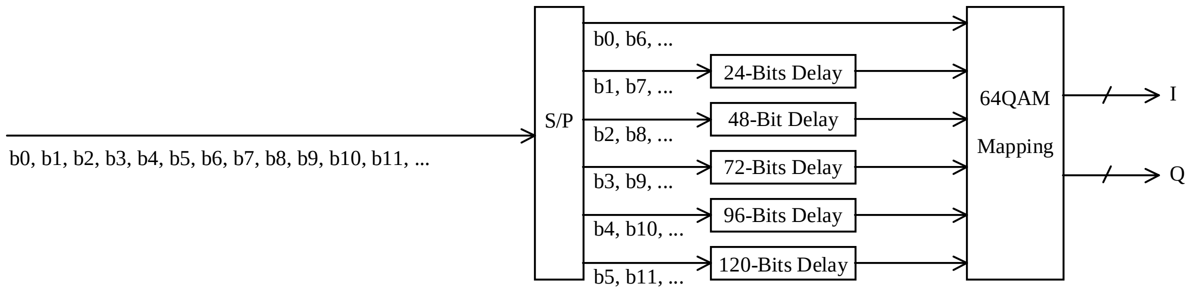


Fig. 4-8 64-QAM modulation

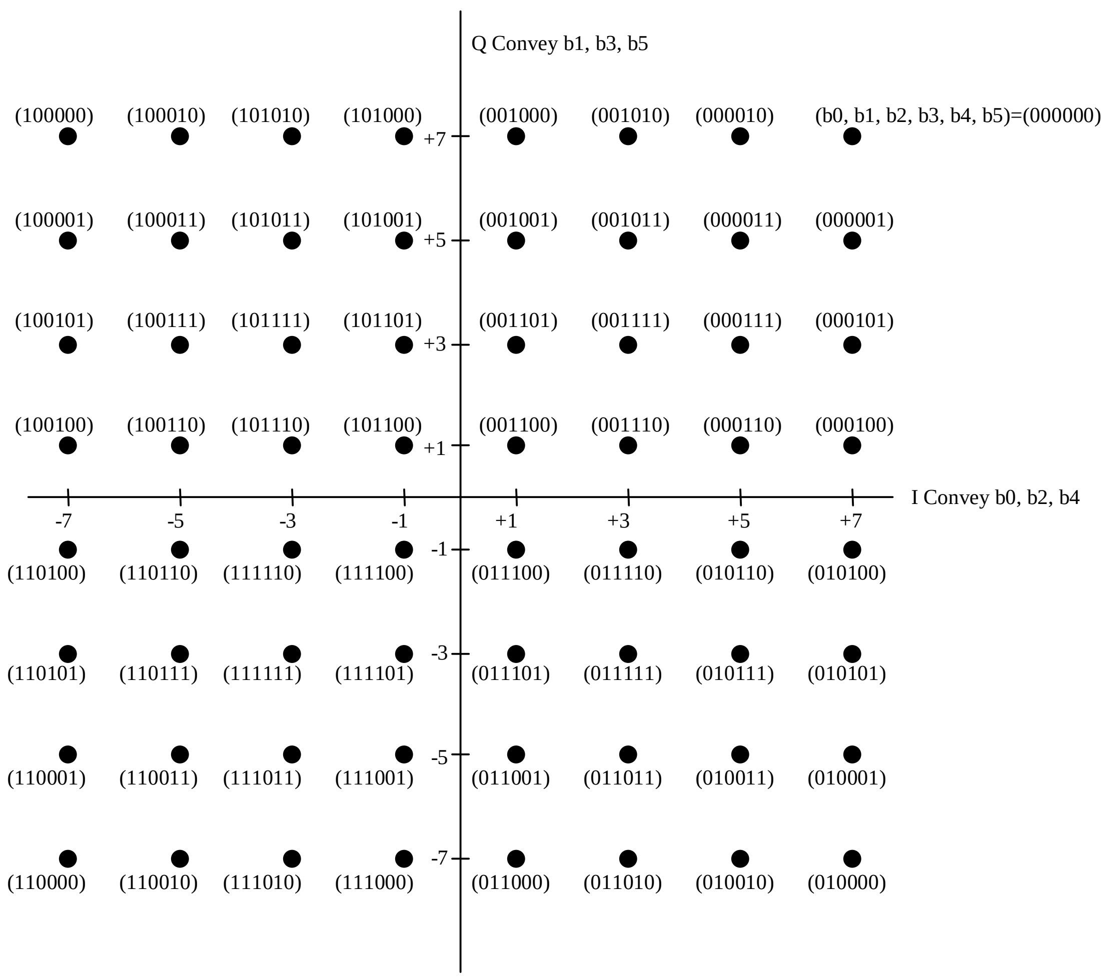


Fig. 4-9 64-QAM mapping

4.3 Normalisation factors

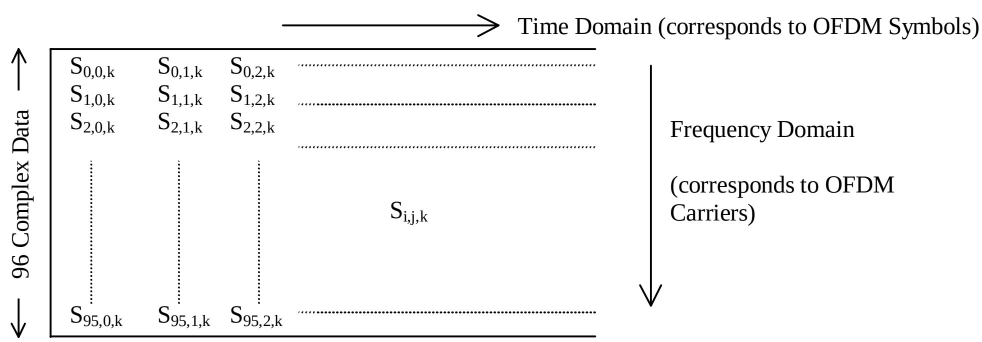
To keep the mean power constant regardless of the kind of modulation, the normalization factor is applied to the constellation point z (=I + jQ) shown on to Figs. 4-3, 4-5, 4-7, and 4-9. By the normalisation according to table 4-2, the mean power is kept constant.

Table 4-2 Normalisation factors for data symbols

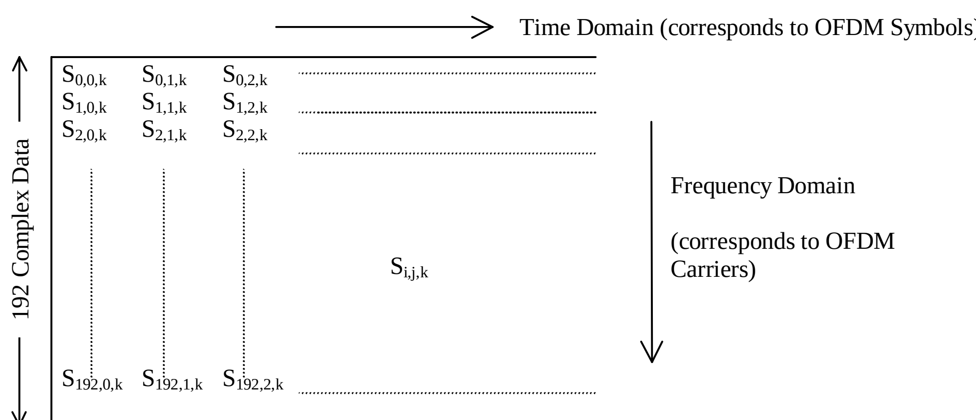
Carrier Modulation	Normalisation Factor
π/4 Shift DQPSK	$Z/\sqrt{2}$
QPSK	$Z/\sqrt{2}$
16QAM	$Z/\sqrt{10}$
64QAM	$Z/\sqrt{42}$

4.4 Data Segment

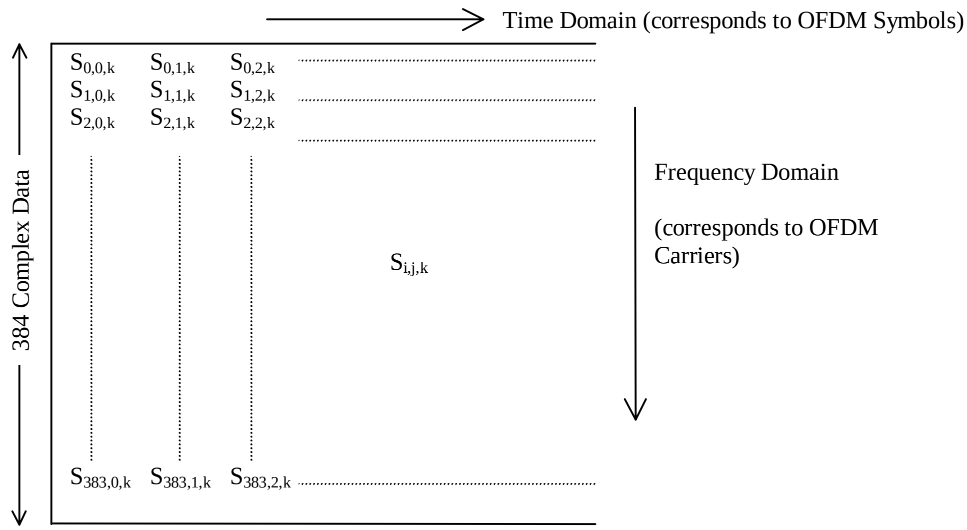
As shown in Fig. 2-17, data segment is defined as a table of addresses for complex data, on which rate conversion, time interleaving, and frequency interleaving shall be executed. The data segment corresponds to the data portion of OFDM segment.



(a) Structure of Data Segment for Mode 1



(b) Structure of Data Segment for Mode 2



(c) Structure of Data Segment for Mode 3

Fig. 4-10 Structure of Data Segment

4.4 Synthesis of layer-data streams

After being channel-coded and mapped, complex data of each layer are inputted to pre-assigned data-segments every one symbol.

The data stored in all data segments are cyclically read with the IFFT-sample clock; then rate conversions and systhesis of layer data streams are carried out (see Fig.4-11).

In Fig. 2-18, the value of n_c equals 96 for Mode 1, 192 for Mode 2, or 384 for Mode 3. In the case of 1-segment transmission only a rare conversion is done.

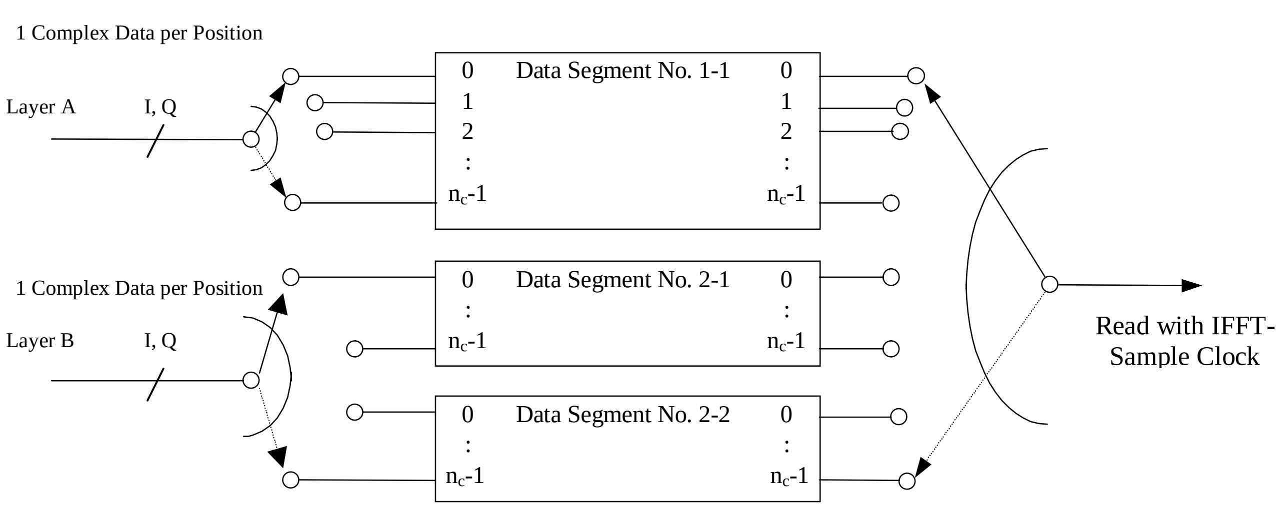


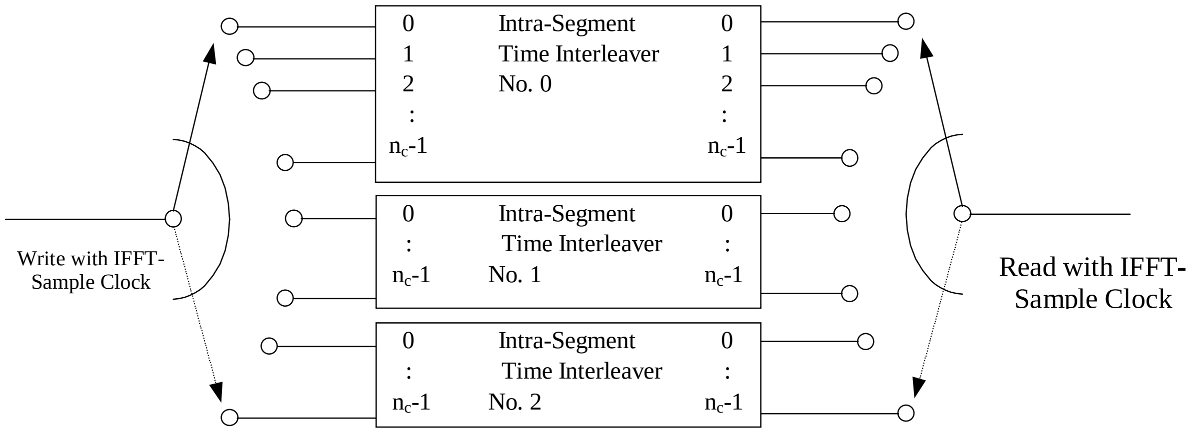
Fig. 4-11 Synthesis of layer-data streams

4.5 Time interleaving

After synthesis, symbol-wise time interleaving is carried out.

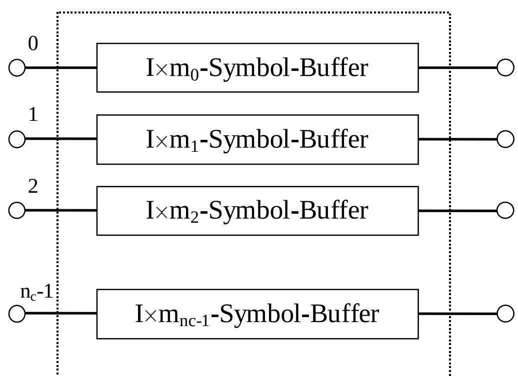
The structure of the intra-segment time-interleaver in the Fig. 4-12 is shown in Fig. 4-13. The integer I is a parameter for the length of time interleaving, and shall be specified for each layer.

For the 1-segment transmission, there is only one segment of No.0.



Where, n_c=96 for Mode 1, 192 for Mode 2, 384 for Mode 3.

Fig. 4-12 Time interleaver for the 3-segment transmission



where, m_j = (j×5) mod 96, and n_c = 96 (Mode 1), 192 (Mode 2), or 384 (Mode 3)

Fig. 4-13 Intra-segment time interleaver

A delay accompanying time interleaving is adjusted in accordance with a integer I as shown in table 4-3. A delay to be compensated for each layer is determined so that the total delay including de-interleaving process in the receiver amounts to an integral number of OFDM-frames.

Table 4-3 Delay adjustment accompanied with time interleaving

Mode 1			Mode 2			Mode 3		
I	Number of symbols for delay adjustment	Number of OFDM Frames to be delayed by delay adjustment and time interleaving	**I**	Number of symbols for delay adjustment	Number of OFDM Frames to be delayed by delay adjustment and time interleaving	**I**	Number of symbols for delay adjustment	Number of OFDM Frames to be delayed by delay adjustment and time interleaving
0	0	0	**0**	0	0	**0**	0	0
4	28	2	**2**	14	1	**1**	109	1
8	56	4	**4**	28	2	**2**	14	1
16	112	8	**8**	56	4	**4**	28	2
32	224	16	**16**	112	8	**8**	56	4

4.6 Frequency interleaving

The configuration of frequency interleaving functional blocks is shown in Fig.4-14. Inter-segment frequency interleaving is taken among the segments having the same modulation scheme.

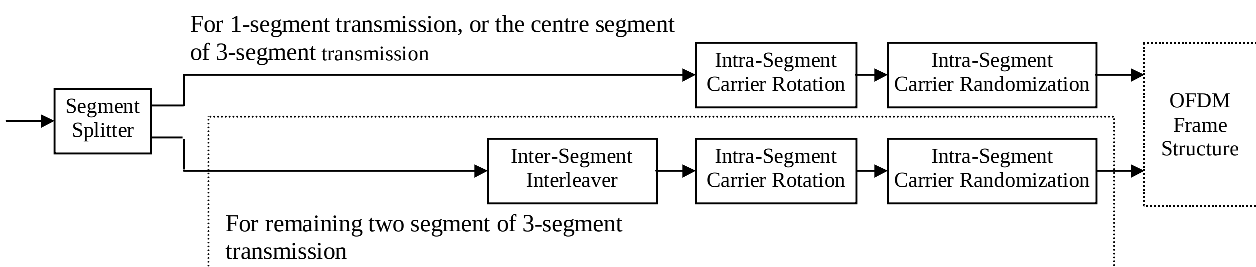


Fig. 4-14 Configuration of frequency interleaver

4.6.1 Inter-segment frequency interleaving

Inter-segment frequency interleaving can be carried out only for two segments of No.1 and 2 of the 3-segment transmission (see Fig.4-21). Because of the partial reception by a 1-segment receiver, the interleaving range for a centre segment of No.0 should be within the segment.

Where, S_{ijk} denotes complex data shown in Fig. 4-10.

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
$S_{0,0,0} = S_0$	$S_{1,0,0} = S_1$	⋯	$S_{95,0,0} = S_{95}$	$S_{0,0,1} = S_{96}$	$S_{1,0,1} = S_{97}$	⋯	$S_{95,0,1} = S_{191}$	$S_{0,0,2} = S_{192}$	$S_{1,0,2} = S_{193}$	⋯	$S_{95,0,2} = S_{287}$

Allocation of Complex Data before Inter-Segment Interleaving

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
S_0	S_1	⋯	S_{95}	S_{96}	S_{98}	⋯	S_{286}	S_{97}	S_{99}	⋯	S_{287}

Allocation of Complex Data after Inter-Segment Interleaving

(a) Inter-segment interleaver for Mode 1

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
$S_{0,0,0} = S_0$	$S_{1,0,0} = S_1$	⋯	$S_{191,0,0} = S_{191}$	$S_{0,0,1} = S_{192}$	$S_{1,0,1} = S_{193}$	⋯	$S_{191,0,1} = S_{383}$	$S_{0,0,2} = S_{384}$	$S_{1,0,2} = S_{385}$	⋯	$S_{191,0,2} = S_{575}$

Allocation of Complex Data before Inter-Segment Interleaving

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
S_0	S_1	⋯	S_{191}	S_{192}	S_{194}	⋯	S_{574}	S_{193}	S_{195}	⋯	S_{575}

Allocation of Complex Data after Inter-Segment Interleaving

(b) Inter-segment interleaver for Mode 2

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
$S_{0,0,0} = S_0$	$S_{1,0,0} = S_1$	⋯	$S_{383,0,0} = S_{383}$	$S_{0,0,1} = S_{384}$	$S_{1,0,1} = S_{385}$	⋯	$S_{383,0,1} = S_{767}$	$S_{0,0,2} = S_{768}$	$S_{1,0,2} = S_{769}$	⋯	$S_{383,0,2} = S_{1151}$

Allocation of Complex Data before Inter-Segment Interleaving

Data Segment No. 0				Data Segment No. 1				Data Segment No. 2			
S_0	S_1	⋯	S_{383}	S_{384}	S_{386}	⋯	S_{1150}	S_{385}	S_{387}	⋯	S_{1151}

Allocation of Complex Data after Inter-Segment Interleaving

(c) Inter-segment interleaver for Mode 3

Fig.4-15 Inter-segment interleaver

4.6.2 Intra-segment interleaving

After carrier rotation according to Fig. 4-16, carrier randomisation is performed as shown in table 4-4.

In Fig. 4-16, $S'_{i,j,k}$ denotes the complex data of the k-th segment after inter-segment interleaving. A segment number 'k' is 0, 1, or 2.

In 1-segment transmission, intra-segment carrier rotation is not applied because of k = 0.

$S'_{0,0,k}$	$S'_{1,0,k}$	$S'_{2,0,k}$	---	$S'_{95,0,k}$

↓

$S'_{(k \bmod 96),0,k}$	$S'_{(k+1 \bmod 96),0,k}$	$S'_{(k+2 \bmod 96),0,k}$	---	$S'_{(k+95 \bmod 96),0,k}$

(a) Intra-segment carrier rotation for Mode 1

$S'_{0,0,k}$	$S'_{1,0,k}$	$S'_{2,0,k}$	---	$S'_{95,0,k}$

↓

$S'_{(k \bmod 192),0,k}$	$S'_{(k+1 \bmod 192),0,k}$	$S'_{(k+2 \bmod 192),0,k}$	---	$S'_{(k+191 \bmod 192),0,k}$

(b) Intra-segment carrier rotation for Mode 2

$S'_{0,0,k}$	$S'_{1,0,k}$	$S'_{2,0,k}$	---	$S'_{383,0,k}$

↓

$S'_{(k \bmod 384),0,k}$	$S'_{(k+1 \bmod 384),0,k}$	$S'_{(k+2 \bmod 384),0,k}$	---	$S'_{(k+383 \bmod 384),0,k}$

(c) Intra-segment carrier rotation for Mode 3

Fig. 4-16 Intra-segment carrier rotation interleaver

Table 4-4 Intra-segment carrier randomisation

(a) Intra-segment carrier randomisation for Mode 1

From	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
To	80	93	63	92	94	55	17	81	6	51	9	85	89	65	52	15	73	66	46	71	12	70	18	13

From	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
To	95	34	1	38	78	59	91	64	0	28	11	4	45	35	16	7	48	22	23	77	56	19	8	36

From	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
To	39	61	21	3	26	69	67	20	74	86	72	25	31	5	49	42	54	87	43	60	29	2	76	84

From	74	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
To	83	40	14	79	27	57	44	37	30	68	47	88	75	41	90	10	33	32	62	50	58	82	53	24

where, numerical values in the table indicate carrier indexes, and complex data indicated by the carrier index in the row "From" is carried by the carrier index in the row "To"

(b) Intra-segment carrier randomisation for Mode 2

From	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
To	98	35	67	116	135	17	5	93	73	168	54	143	43	74	165	48	37	69	154	150	107	76	176	79

From	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
To	175	36	28	78	47	128	94	163	184	72	142	2	86	14	130	151	114	68	46	183	122	112	180	42

From	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
To	105	97	33	134	177	84	170	45	187	38	167	10	189	51	117	156	161	25	89	125	139	24	19	57

From	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
To	71	39	77	191	88	85	0	162	181	113	140	61	75	82	101	174	118	20	136	3	121	190	120	92

From	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
To	160	52	153	127	65	60	133	147	131	87	22	58	100	111	141	83	49	132	12	155	146	102	164	66

From	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
To	1	62	178	15	182	96	80	119	23	6	166	56	99	123	138	137	21	145	185	18	70	129	95	90

From	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167
To	149	109	124	50	11	152	4	31	172	40	13	32	55	159	41	8	7	144	16	26	173	81	44	103

From	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
To	64	9	30	157	126	179	148	63	188	171	106	104	158	115	34	186	29	108	53	91	169	110	27	59

where, numerical values in the table indicate carrier indexes, and complex data indicated by the carrier index in the row "From" is carried by the carrier index in the row "To"

(c) Intra-segment carrier randomisation for Mode 3

From	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
To	62	13	371	11	285	336	365	220	226	92	56	46	120	175	298	352	172	235	53	164	368	187	125	82

From	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
To	5	45	173	258	135	182	141	273	126	264	286	88	233	61	249	367	310	179	155	57	123	208	14	227

From	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
To	100	311	205	79	184	185	328	77	115	277	112	20	199	178	143	152	215	204	139	234	358	192	309	183

From	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
To	81	129	256	314	101	43	97	324	142	157	90	214	102	29	303	363	261	31	22	52	305	301	293	177

From	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
To	116	296	85	196	191	114	58	198	16	167	145	119	245	113	295	193	232	17	108	283	246	64	237	189

From	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
To	128	373	302	320	239	335	356	39	347	351	73	158	276	243	99	38	287	3	330	153	315	117	289	213

From	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167
To	210	149	383	337	339	151	241	321	217	30	334	161	322	49	176	359	12	346	60	28	229	265	288	225

From	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
To	382	59	181	170	319	341	86	251	133	344	361	109	44	369	268	257	323	55	317	381	121	360	260	275

From	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
To	190	19	63	18	248	9	240	211	150	230	332	231	71	255	350	355	83	87	154	218	138	269	348	130

From	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239
To	160	278	377	216	236	308	223	254	25	98	300	201	137	219	36	325	124	66	353	169	21	35	107	50

From	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263
To	106	333	326	262	252	271	263	372	136	0	366	206	159	122	188	6	284	96	26	200	197	186	345	340

From	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287
To	349	103	84	228	212	2	67	318	1	74	342	166	194	33	68	267	111	118	140	195	105	202	291	259

From	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311
To	23	171	65	281	24	165	8	94	222	331	34	238	364	376	266	89	80	253	163	280	247	4	362	379

From	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335
To	290	279	54	78	180	72	316	282	131	207	343	370	306	221	132	7	148	299	168	224	48	47	357	313

From	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359
To	75	104	70	147	40	110	374	69	146	37	375	354	174	41	32	304	307	312	15	272	134	242	203	209

From	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383
To	380	162	297	327	10	93	42	250	156	338	292	144	378	294	329	127	270	76	95	91	244	274	27	51

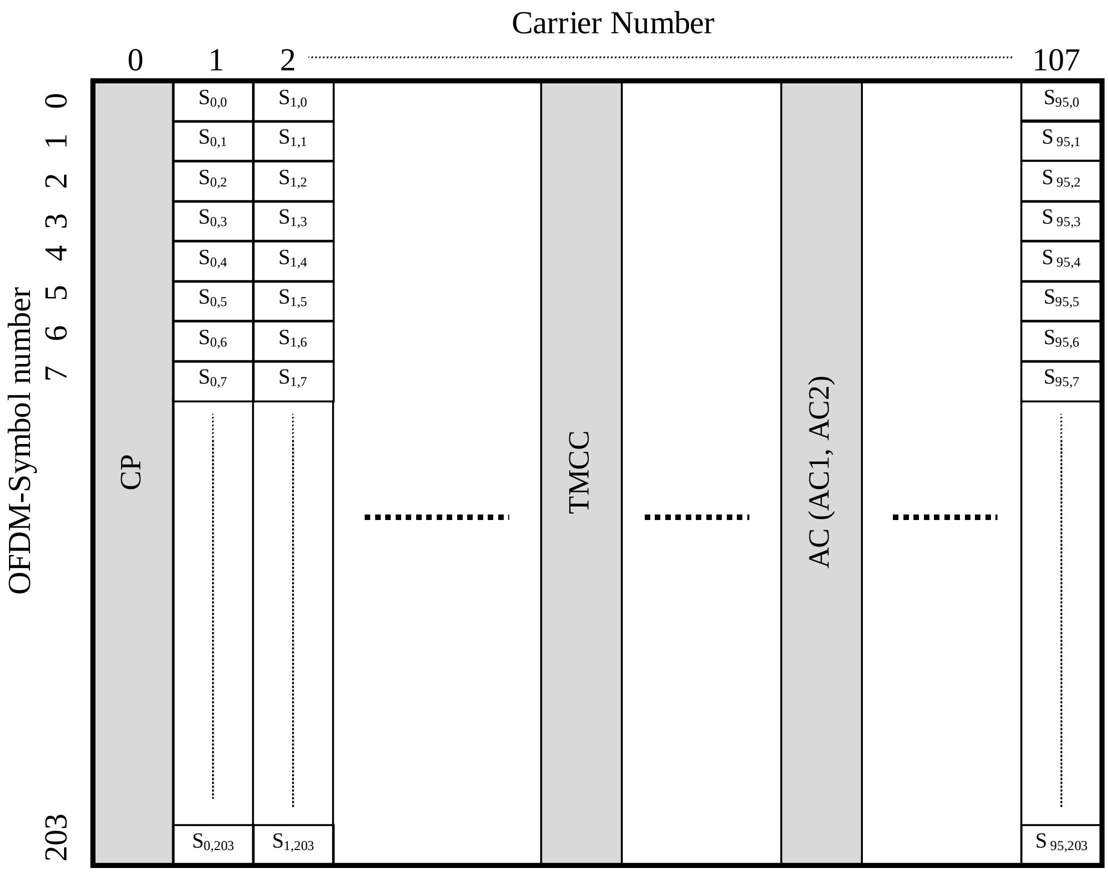
where, numerical values in the table indicate carrier indexes, and complex data indicated by the carrier index in the row “From” is carried by the carrier index in the row “To”

4.7 OFDM segment-frame structure

By adding pilots, data segments are arranged into OFDM segment-frame every 204 symbols.

4.7.1 OFDM segment-frame for differential modulation

As an example, OFDM segment-frame for differential modulation (DQPSK) is shown about Mode 1 in Fig. 4-17.



where, $S_{i,j}$ denotes the complex data in a data segment after time and frequency interleaving.
The modulation phase of CP (Continual Pilot) is constant at all time.
TMCC (Transmission and Multiplexing Configuration Control) carrier carries the control data.
AC (Auxiliary Channel) carrier carries the ancillary information.
Allocation of these pilot carriers is shown in table 4-5.

Fig. 4-17 Structure of OFDM segment for differential modulation

Table 4-5 Carrier allocation of CP, AC, and TMCC for differential modulation

(a) Carrier allocation of CP, AC, and TMCC for Mode 1

Segment Number	1	0	2
CP	0	0	0
AC1_ 1	74	35	76
AC1_ 2	100	79	97
AC2_ 1	30	3	5
AC2_ 2	81	72	18
AC2_ 3	92	85	57
AC2_ 4	103	89	92
TMCC 1	7	49	31
TMCC 2	25	61	39
TMCC 3	47	96	47
TMCC 4	60	99	65
TMCC 5	87	104	72

(b) Carrier allocation of CP, AC, and TMCC for Mode 2

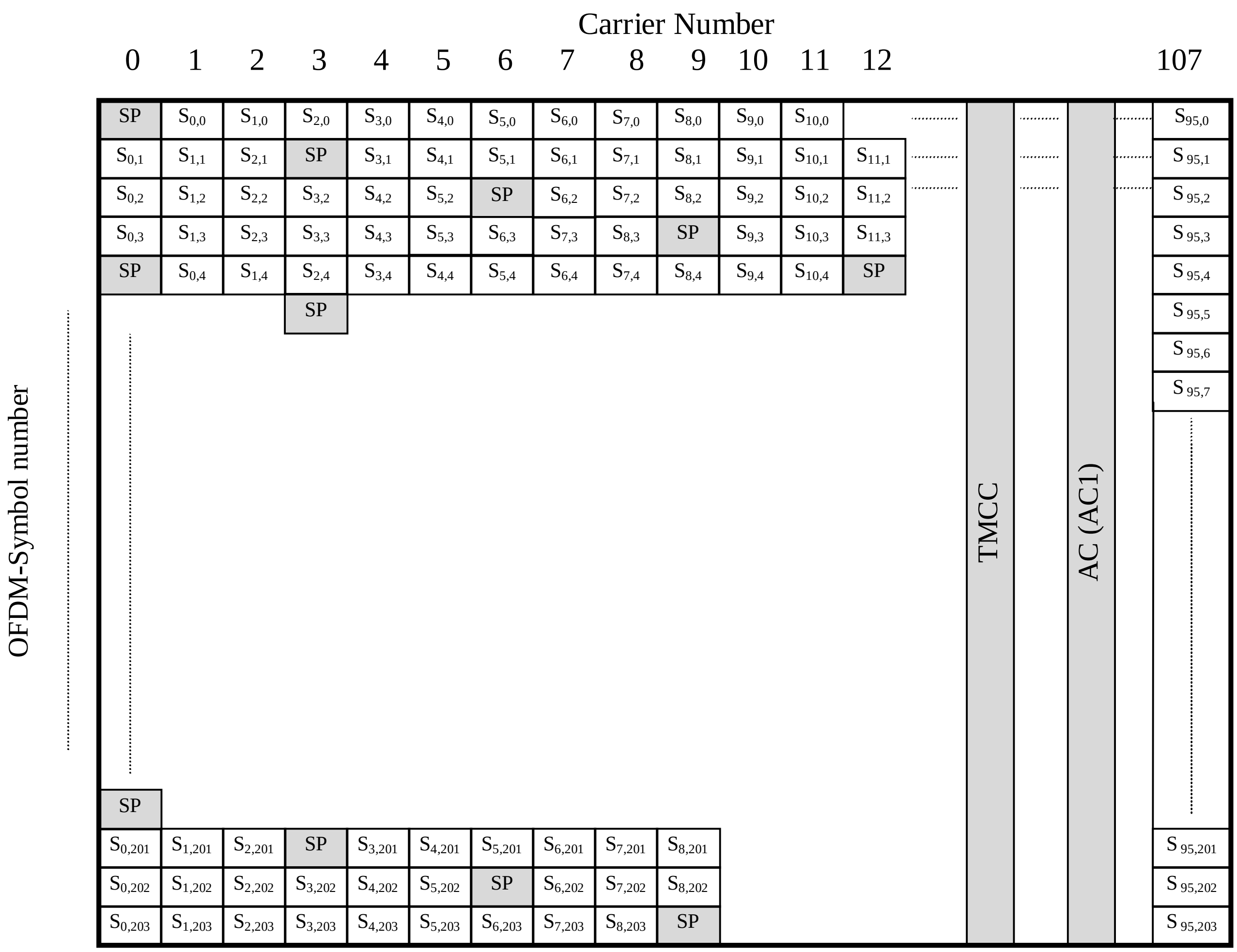
Segment Number	1	0	2
CP	0	0	0
AC1_ 1	8	98	53
AC1_ 2	64	101	83
AC1_ 3	115	118	169
AC1_ 4	197	136	208
AC2_ 1	36	10	3
AC2_ 2	48	30	15
AC2_ 3	52	55	40
AC2_ 4	74	81	58
AC2_ 5	108	108	108
AC2_ 6	133	111	137
AC2_ 7	138	153	149
AC2_ 8	150	167	192
AC2_ 9	212	185	201
TMCC 1	78	23	25
TMCC 2	82	37	63
TMCC 3	85	51	73
TMCC 4	98	68	80
TMCC 5	102	105	93
TMCC 6	142	121	112
TMCC 7	156	158	115
TMCC 8	162	178	125
TMCC 9	178	191	159
TMCC 10	209	195	179

(c) Carrier allocation of CP, AC, and TMCC for Mode 3

Segment Number	1	0	2
CP	0	0	0
AC1_ 1	76	7	61
AC1_ 2	97	89	100
AC1_ 3	112	206	119
AC1_ 4	197	209	209
AC1_ 5	256	226	236
AC1_ 6	305	244	256
AC1_ 7	332	377	398
AC1_ 8	388	407	424
AC2_ 1	5	25	29
AC2_ 2	18	30	41
AC2_ 3	57	42	84
AC2_ 4	92	104	93
AC2_ 5	108	108	108
AC2_ 6	121	118	136
AC2_ 7	201	138	153
AC2_ 8	206	163	189
AC2_ 9	210	189	199
AC2_ 10	216	216	216
AC2_ 11	288	219	239
AC2_ 12	311	261	279
AC2_ 13	316	275	301
AC2_ 14	321	293	321
AC2_ 15	324	324	324
AC2_ 16	360	327	354
AC2_ 17	372	339	405
AC2_ 18	376	364	416
AC2_ 19	398	382	427
TMCC 1	31	34	4
TMCC 2	39	48	7
TMCC 3	47	54	17
TMCC 4	65	70	51
TMCC 5	72	101	71
TMCC 6	124	131	144
TMCC 7	138	145	156
TMCC 8	145	159	163
TMCC 9	182	176	167
TMCC 10	191	213	194
TMCC 11	221	229	226
TMCC 12	226	266	244
TMCC 13	237	286	260
TMCC 14	260	299	263
TMCC 15	277	303	270
TMCC 16	402	349	331
TMCC 17	406	387	349
TMCC 18	409	397	371
TMCC 19	422	404	384
TMCC 20	426	417	411

4.7.2 OFDM segment-frame for coherent modulation

As an example, OFDM segment-frame for coherent modulation (QPSK, 16QAM, 64QAM) is shown about Mode 1 in Fig. 4-18.



where, $S_{i,j}$ denotes the complex data in the data segment after time and frequency interleaving.
SP (Scattered Pilot) is inserted in every 12 carriers and in every 4 OFDM symbols.
Allocation of AC and TMCC is shown in table 4-6.

Fig. 4-18 Structure of OFDM segment for coherent modulation

Table 4-6 Carrier allocations of AC and TMCC for coherent modulation

(a) Carrier allocation of AC and TMCC for Mode 1

Segment Number	1	0	2
AC1_ 1	74	35	76
AC1_ 2	100	79	97
TMCC 1	47	49	31

(b) Carrier allocation of AC and TMCC for Mode 2

Segment Num-ber	1	0	2
AC1_ 1	8	98	53
AC1_ 2	64	101	83
AC1_ 3	115	118	169
AC1_ 4	197	136	208
TMCC 1	85	23	25
TMCC 2	209	178	125

(c) Carrier allocation of AC and TMCC for Mode 3

Segment Num-ber	1	0	2
AC1_ 1	76	7	61
AC1_ 2	97	89	100
AC1_ 3	112	206	119
AC1_ 4	197	209	209
AC1_ 5	256	226	236
AC1_ 6	305	244	256
AC1_ 7	332	377	398
AC1_ 8	388	407	424
TMCC 1	31	101	17
TMCC 2	191	131	194
TMCC 3	277	286	260
TMCC 4	409	349	371

4.7.3 Modulation schemes for pilots

Every carrier of four kinds of pilots is DBPSK-modulated and conveys the dedicated information for each pilot.

(a) Scattered Pilot (SP)

The scattered pilots are modulated according to a PBRS sequence, ‘W_i’, corresponding to their carrier index ‘i’. Amplitude of ‘W_i’ is boosted as shown in table 4-7. The PBRS sequence is generated according to figure 4-19.

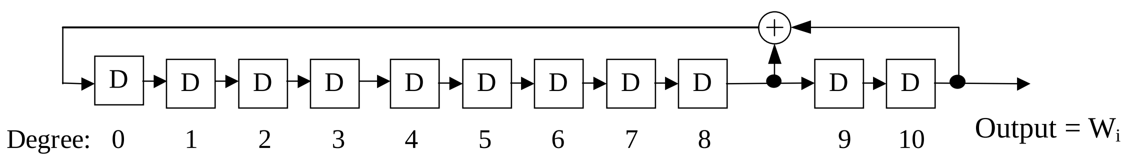
The PRBS is initialised so that the first bit from the PRBS coincides with the first active carrier of a segment. A new value is generated by the PRBS on every used carrier (whether or not it is a pilot).

Initial set of the PRBS register is defined according to what sub-channel the centre frequency of a segment belongs to as shown in table 4-8.

The sub-channel number is defined in figure 4-20. A sub-channel is simply a virtual channel with a bandwidth of 1/7 MHz.

An example of a segment having a sub-channel 22 in the centre is shown in this figure. This segment is composed of sub-channels 21, 22, and 23.

It should be noted for the partial reception that ‘W_i’ of the 1-segment transmission having a sub-channel 22 in the centre coincides with that of the centre segment in the wide band ISDB-T.



$$g(x) = x^{11} + x^{9} + 1$$

Fig. 4-19 Generation of PRBS sequence

Table 4-7 Boosted power level of pilots

W_i	Complex Value of Pilot Signal (I, Q)
1	(-4/3, 0)
0	(+4/3, 0)

Table 4-8 Initial sets of PRBS register

Center Sub-channel Number of a Segment	Initial Sets for Mode 1 (Degree from 0 to 10 in Fig.4-19)	Initial Sets for Mode 2 (Degree from 0 to 10 in Fig4-19)	Initial Sets for Mode 3 (Degree from 0 to 10 in Fig.4-19)
41, 0, 1	1 1 1 0 0 1 0 0 1 0 1	0 0 0 1 1 0 1 1 1 1 0	1 1 1 0 0 0 1 1 1 0 1
2, 3, 4	1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1
5, 6, 7	1 1 0 1 1 0 0 1 1 1 1	0 1 1 0 1 0 1 1 1 1 0	1 1 0 1 1 1 0 0 1 0 1
8, 9, 10	0 1 1 0 1 0 1 1 1 1 0	1 1 0 1 1 1 0 0 1 0 1	1 0 0 1 0 1 0 0 0 0 0
11, 12, 13	0 1 0 0 0 1 0 1 1 1 0	1 1 0 0 1 0 0 0 0 1 0	0 1 1 1 0 0 0 1 0 0 1
14, 15, 16	1 1 0 1 1 1 0 0 1 0 1	1 0 0 1 0 1 0 0 0 0 0	0 0 1 0 0 0 1 1 0 0 1
17, 18, 19	0 0 1 0 1 1 1 1 0 1 0	0 0 0 0 1 0 1 1 0 0 0	1 1 1 0 0 1 1 0 1 1 0
20, 21, 22	1 1 0 0 1 0 0 0 0 1 0	0 1 1 1 0 0 0 1 0 0 1	0 0 1 0 0 0 0 1 0 1 1
23, 24, 25	0 0 0 1 0 0 0 0 1 0 0	0 0 0 0 0 1 0 0 1 0 0	1 1 1 0 0 1 1 1 1 0 1
26, 27, 28	1 0 0 1 0 1 0 0 0 0 0	0 0 1 0 0 0 1 1 0 0 1	0 1 1 0 1 0 1 0 0 1 1
29, 30, 31	1 1 1 1 0 1 1 0 0 0 0	0 1 1 0 0 1 1 1 0 0 1	1 0 1 1 1 0 1 0 0 1 0
32, 33, 34	0 0 0 0 1 0 1 1 0 0 0	1 1 1 0 0 1 1 0 1 1 0	0 1 1 0 0 0 1 0 0 1 0
35, 36, 37	1 0 1 0 0 1 0 0 1 1 1	0 0 1 0 1 0 1 0 0 0 1	1 1 1 1 0 1 0 0 1 0 1
38, 39, 40	0 1 1 1 0 0 0 1 0 0 1	0 0 1 0 0 0 0 1 0 1 1	0 0 0 1 0 0 1 1 1 0 0

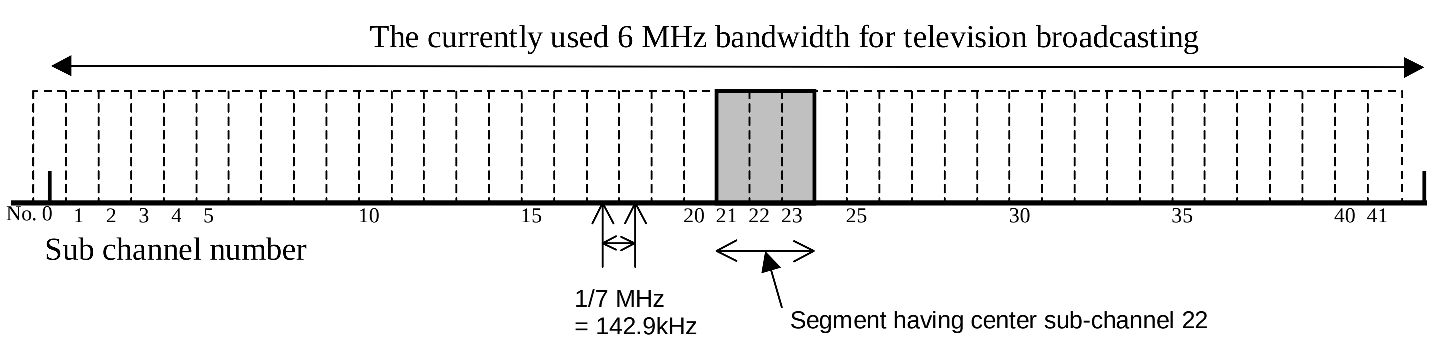


Fig. 4-20 Definition of sub-channel

(b) Continual pilot

The continual pilots are modulated in the same way as scattered pilots. The modulation phase of the continual pilots is constant in all symbols, and 'Wi' governs its value. Carrier Allocation of CP in Segment is shown in figure 4-17.

(c) TMCC

The reference bit for differential modulation is the first bit of TMCC data, and 'Wi' also governs its value. Information bits of B_1 to B_{203} are differential-coded to B'_0 to B'_{203} by the next algorithm.

$B'_0 = Wi$: Initialisation bit for the DBPSK modulation

$B'_k = B'_{k-1} \oplus B_k$: k=1, 203, $\oplus$ indicates exclusive OR

Coded bit B' = 0, 1 are converted to (+4/3,0), (-4/3,0).

(d) AC

The modulation scheme for AC is the same as that of TMCC. In the case of no ancillary information, "1" is applied for B_k as a stuffing bit.

4.7.4 Transmission spectrum

Segments are numbered in accordance with figure 4-21. In the 3-segment transmission, the centre segment should be dedicated for the partial reception by a 1-segment receiver.

A continuous pilot (CP) should be added at the edge of an upper side segment when a coherent modulation scheme is applied for the segment.

The right end (upper end) of the band is used for continuous-carrier arrangement (Additional CP).

'W_i' of the additional CP is continuously defined as the next output bit from PRBS.

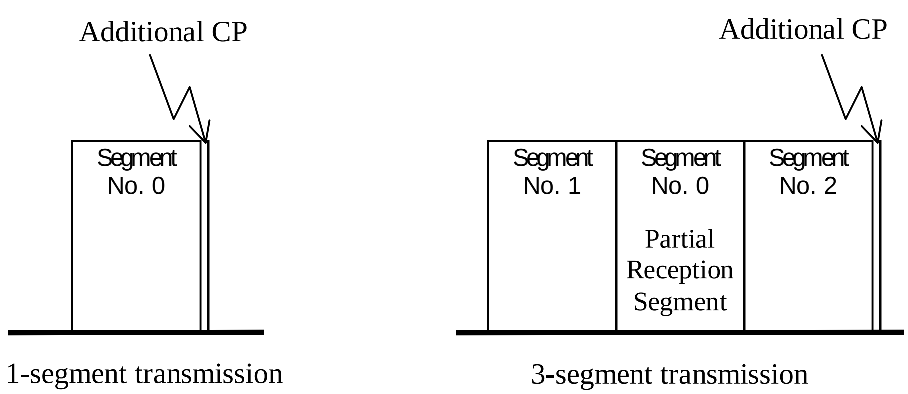


Fig. 4-21 Segment number in transmission spectrum

4.8 RF signal format

The emitted signal is described by the following expression:

$$s(t) = Re\left\{ e^{j2\pi f_c t} \sum_{n=0}^{\infty} \sum_{k=0}^{K-1} c(n,k)\Psi(n,k,t) \right\}$$

where,

$$\Psi(n,k,t) = \begin{cases} e^{j2\pi \frac{k-Kc}{Tu}(t-Tg-nTs)} & nTs \le t < (n+1)Ts \\ 0 & t < nTs, \quad (n+1)Ts \le t \end{cases}$$

where,

- k denotes the carrier index numbered from 0^{th} carrier of the lowest segment;
- n denotes the OFDM symbol number;
- K is the number of transmitted carriers (109 for Mode 1, 217 for Mode 2, 433 for Mode 3 in 1-segment transmission and 325 for Mode 1, 649 for Mode 2, 1297 for Mode 3 in 3-segment transmission);

- Ts is the symbol duration (= Tg + Tu);
- Tg is the duration of the guard interval;
- Tu is the duration of effective symbol;
- fc is the center frequency of RF signal;
- Kc is the carrier index of the centre frequency of RF signal (54 for Mode 1, 108 for Mode 2, 216 for Mode 3 in 1-segment transmission and 162 for Mode 1, 324 for Mode 2, 648 for Mode 3 in 3-segmenttransmission);

- c(n,k) is complex data of n-th OFDM-symbol carried by k-th carrier number;
- s(t) is an RF signal.

4.9 Insertion of Guard Interval

A guard interval is inserted as shown in figure 4-22 where a replica of back-end data from IFFT is placed in front of effective symbol data. The length of the replica corresponds to the duration of the guard interval.

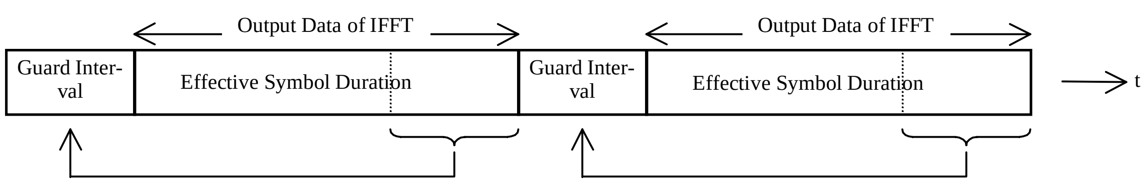


Fig. 4-22 Guard Interval

5. Transmission and Multiplexing Configuration Control (TMCC)

This section specifies information coding and transmission scheme of the TMCC signal.

The TMCC signal is used to transmit, for example, hierarchical information, transmission parameters of each OFDM segment, and information related to demodulation operations on the receiver. This signal is transmitted using the TMCC carrier specified in sub clause 4.7.

5.1 TMCC transmission format

The 204 bits of B_0 to B_{203} per carrier are assigned as shown in table 3-1.

Table 3-1 Bit assignment for TMCC

B_0	Initialisation bit for the DBPSK modulation
B_1 - B_{16}	Synchronization word (w0 = 0011010111101110, w1 = 1100101000010001)
B_{17} - B_{19}	Segment Descriptor (Deferential Modulation: 111, Coherent Modulation: 000)
B_{20} - B_{121}	TMCC Information (102 bits, See Table 3-2)
B_{122} - B_{203}	Parity Bits

5.2 Reference to differential demodulation

The references of phase and amplitude for demodulation are given also with 'Wi' according to table 4-8.

5.3 Synchronisation of TMCC

A 16-bit synchronization sequence takes w_0 and w_1 (the inverse of w_0) in turn in every frame.

Where:

w_0 is [0011010111101110];

w_1 is [1100101000010001].

5.4 Segment type identification

Differential modulation segment is identified with the ID of "111" and coherent modulation segment is identified with the ID of "000".

5.5 TMCC information

The TMCC information composed of system descriptor, countdown index, switch-on flag for alert broadcasting, current configuration and next configuration.

table 5-2 shows bit assignment for TMCC information. table 5-3 shows contents of transmission parameters. The 90 bits of 102 whole bits are used as shown at present. The remaining 12 bits are reserved for future use, and should be set to “1”.

The bit assignment for TMCC information coincides with that wide band ISDB-T to maintain compatibility even though there are no B and C layers in the 1-segment transmission and no C layer in the 3-segment transmission. In these cases, default bits for unused function are applied.

Table 5-2 Bit assignment for TMCC information

Information bits	Number of Bit	Function		Reference
B_{20} - B_{21}	2	System Descriptor		Table 5-4
B_{22} - B_{25}	4	Count Down Index		Table 5-5
B_{26}	1	Switch-on Control Flag used for Alert Broadcasting		Table 5-6
B_{27}	1	Current Configuration Information	Transmission segment Identification Flag	Table 5-7
B_{28} - B_{40}	13		Transmission Parameters for Layer A	Table 5-3
B_{41} - B_{53}	13		Transmission Parameters for Layer B	
B_{54} - B_{66}	13		Transmission Parameters for Layer C	
B_{67}	1	Next Configuration Information	Transmission segment Identification Flag	Table 5-7
B_{68} - B_{80}	13		Transmission Parameters for Layer A	Table 5-3
B_{81} - B_{93}	13		Transmission Parameters for Layer B	
B_{94} - B_{106}	13		Transmission Parameters for Layer C	
B_{107} – B_{109}	3	Phase correction of CP in connected transmission		Table 5-12
B_{110} - B_{121}	12	Reserved for Future Use		All set to “1”

Table 5-3 Transmission parameters

	Number of Bits	Reference
Modulation	3	Table 3-8
Code Rate	3	Table 3-9
Time Interleaving	3	Table 3-10
Number of Segments	4	Table 3-11

5.5.1 System identification

The ISDB-T family is identified by two bits. An ID of “00” is assigned to the wide band ISDB-T system using 13 segments for television, and “01” is assigned to the system described by this specification. The remaining bits are reserved.

Table 5-4 System descriptor

B_{20} - B_{21}	System
00	ISDB-T using 13 Segments
01	ISDB-T using 1 or 3 Segments
10, 11	Reserved

5.5.2 Index for transmission parameter change

By counting down the index for transmission parameter change, the change timing is informed to the receiver. The count down starts from 15 OFDM frames before a change. It should be noted that the next of index “0000” is “1111”. The change shall be carried out at the time when the frame-synchronization word is transmitted following the index of “0000”. In other words, new transmission parameters shall be applied to receivers from the frame at which the index returns to “1111”.

Table 5-5 Countdown index

B_{22} - B_{25}	Meaning
1111	Ordinary
1110	15 Frames before Changing Transmission Parameters
1101	14 Frames before Changing Transmission Parameters
1100	13 Frames before Changing Transmission Parameters
:	:
0010	3 Frames before Changing Transmission Parameters
0001	2 Frames before Changing Transmission Parameters
0000	1 Frame before Changing Transmission Parameters
1111	Use New Transmission Parameters

5.5.3 Activation flag for alert broadcasting

As shown table 5-6, while alert broadcasting continues the flag takes “1”, but otherwise the flag takes “0”.

Table 5-6 Switch-on control flag used for alert broadcasting

B_{26}	
0	Ordinary
1	Switch-on

5.5.4 Format identification flag

This flag is ‘0’ for the 1-segment transmission and ‘1’ for the 3-segment transmission. Bit allocation of this flag is shown in Table 3-7.

Table 5-7 Transmission-segment identification flag

B_{27}, / B_{67}	Meaning
0	1-segment transmission
1	3-segment transmission

5.5.5 Modulation scheme

For the identification of modulation schemes, three-bit words are assigned as shown table 5-8. In an unused layer, the word takes “111”. When next configuration-information is not valid, the word also takes “111”.

Table 5-8 Modulation scheme for OFDM carriers

First 3 bits of 13 bits for layer parameter information	Modulation
000	DQPSK
001	QPSK
010	16QAM
011	64QAM
100 – 110	Reserved
111	Unused Layer

5.5.6 Coding rate of inner code

For the identification of the coding rate of convolutional codes, three-bit-words are used as shown in table 5-9. In a layer being not transmitted, the word takes “111”. When next configuration-information is not valid, the word also takes “111”.

Table 5-9 Code rates of inner code

Second 3bits of 13 bits for layer parameter information (see table 5-3)	Code Rate
000	1/2
001	2/3
010	3/4
011	5/6
100	7/8
101 - 110	Reserved
111	Un-used Layer

5.5.7 Length of time interleaving

For the identification of the length of time interleaving, three-bit-words are used as shown table 5-10. In a layer being not transmitted, the word takes "111". When next configuration-information is not valid, the word also takes "111".

Table 5-10 Time interleaving

Third 3 bits of 13 bits for layer parameter information (see table 5-3)	Time Interleaving Parameter I [*1]
000	0 (Mode 1), 0 (Mode 2), 0 (Mode 3)
001	4 (Mode 1), 2 (Mode 2), 1 (Mode 3)
010	8 (Mode 1), 4 (Mode 2), 2 (Mode 3)
011	16 (Mode 1), 8 (Mode 2), 4 (Mode 3)
100	32 (Mode 1), 16 (Mode 2), 8 (Mode 3)
101 - 110	Reserved
111	Un-used Layer

[*1]: See table 4-3

5.5.8 Number of segments

To indicate the number of segments used for each layer, four-bit words are assigned as shown table 5-11. In an unused layer, the word takes "1111". When next configuration-information is not valid, the word also takes "1111".

Table 5-11 Number of segments used in a layer

Last 3 bits of 13 bits for layer parameter information (see table 5-3)	Number of Segments used in the Layer
0000	Reserved
0001	1
0010	2
0011 – 1110	Reserved
1111	Un-used Layer

5.5.9• Phase correction of the first carrier of upper adjacent segment

This function is applied for a connected transmission of segments (see sub-clause 8).

A coherently modulated segment in a connected transmission substitutes the first carrier of upper adjacent segment for its additional CP (see figure 4-21).

In this case, corresponding to a segment position in a connected spectrum, some amount of phase correction should be applied for the first carrier of upper adjacent segment.

Three bits are used for an amount of phase correction as shown table 5-12.

Table 5-12 Amount of phase correction in concatenated transmission

B_{107} $B_{108}B_{109}$	Amount of phase correction($\times 2\pi$)
000	-1/8
001	-2/8
010	-3/8
011	-4/8
100	-5/8
101	-6/8
110	-7/8
111	0 (no phase correction)

5.5.10 Channel coding for TMCC information

Except for the synchronization bits, information bits B_{20} to B_{121} are coded by (184,102) shortened code, derived from the original CDSC (273,191) code.

Code generator polynomial:

$$
\begin{aligned}
g(x) = {} & x^{82} + x^{77} + x^{76} + x^{71} + x^{67} + x^{66} + x^{56} + x^{52} + x^{48} \\
& + x^{40} + x^{36} + x^{34} + x^{24} + x^{22} + x^{18} + x^{10} + x^{4} + 1
\end{aligned}
$$

5.5.11 Modulation of TMCC carriers

TMCC carriers are modulated in the DBPSK scheme (see sub-clause 4.7.3(c)).

6. Auxiliary channel (AC)

The auxiliary channel (AC) is provided for ancillary data besides the broadcasting channel that is transmitting video, audio and data by MPEG-2 TS. It has two sub-channels: AC1 and AC2, whose allocations are shown tables 4-5 and 4-6.

It should be noted that the channel coding schemes for the AC would be specified after the application of the AC channel has been determined.

6.1 Transmission capacity

The modulation scheme for AC is DBPSK as described in section 5. Except for the first symbol used for the phase reference, each AC carrier can convey 203 bits per frame. The transmission capacities of AC1 and AC2 are shown in tables 6-1and 6-2.

It should be noted that the capacity of AC2 depends on the number of differential modulation segments.

Table 6-1 Transmission bit-rates of AC1

Number of Segments	Number of AC1 Carriers (Mode 1/ 2/ 3)	Transmission Rates (kbps)			
		Guard Interval Rate 1/4	Guard Interval Rate 1/8	Guard Interval Rate 1/16	Guard Interval Rate 1/32
1	(2 / 4 / 8)	6.31	7.02	7.43	7.66
3	(6 /12 /24)	18.95	21.06	22.30	22.97

Table 6-2 Transmission bit-rates of AC2 per segment

Number of Segments	Mode	Number of AC2 Carriers	Transmission Rates (kbps)			
			Guard Interval Rate 1/4	Guard Interval Rate 1/8	Guard Interval Rate 1/16	Guard Interval Rate 1/32
1	1	4	12.63	14.04	14.86	15.31
	2	9	14.21	15.79	16.72	17.23
	3	19	15.00	16.67	17.65	18.18

7 Receiving system

This section describes the block diagrams of the receiver and the model receiver that prescribe the algorithm used for making the multiplex frame.

7.1 Functional block diagram

Examples of the block diagrams of a narrow-band ISDB-T receiver are shown in Fig. 7-1.

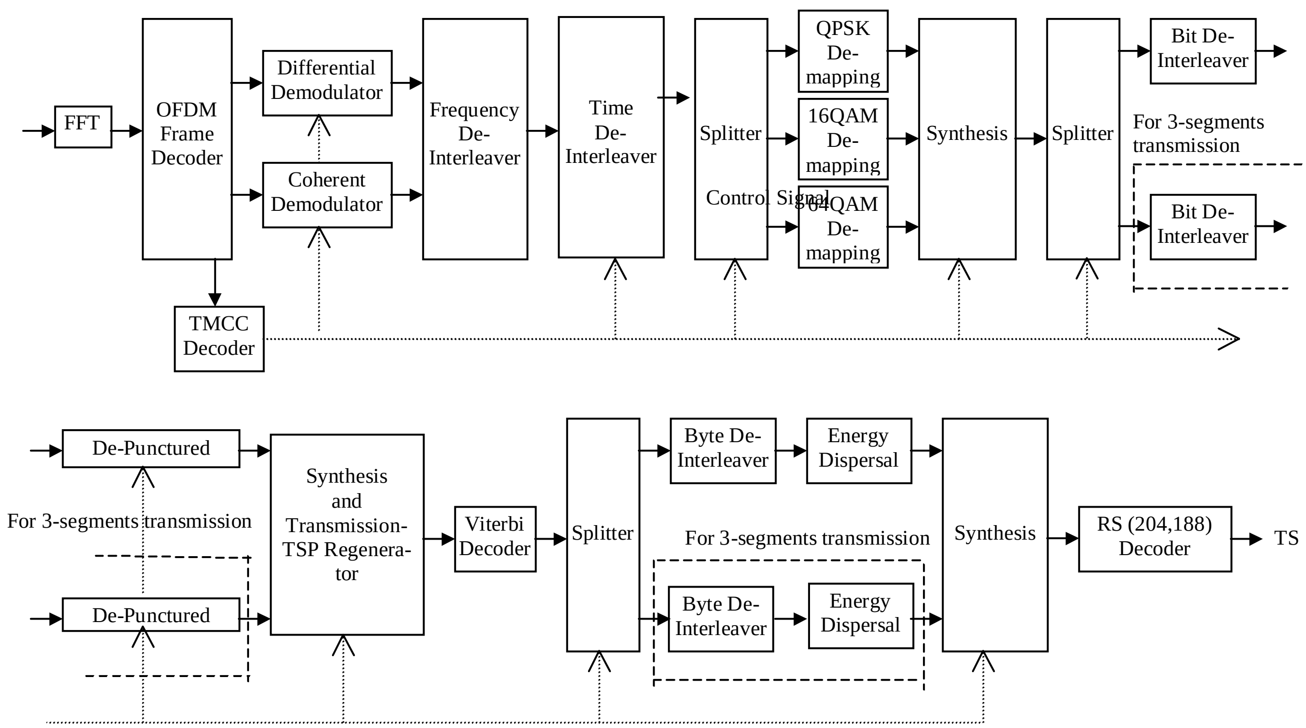


Fig. 7-1 Functional block diagrams of receiver

7.2 Model receiver for composition of Multiplex Frame

The allocation of TSPs in the multiplex frame should be determined in accordance with the operation of a model receiver to reproduce TS. The concept of the receiver is shown in figure 7-2.

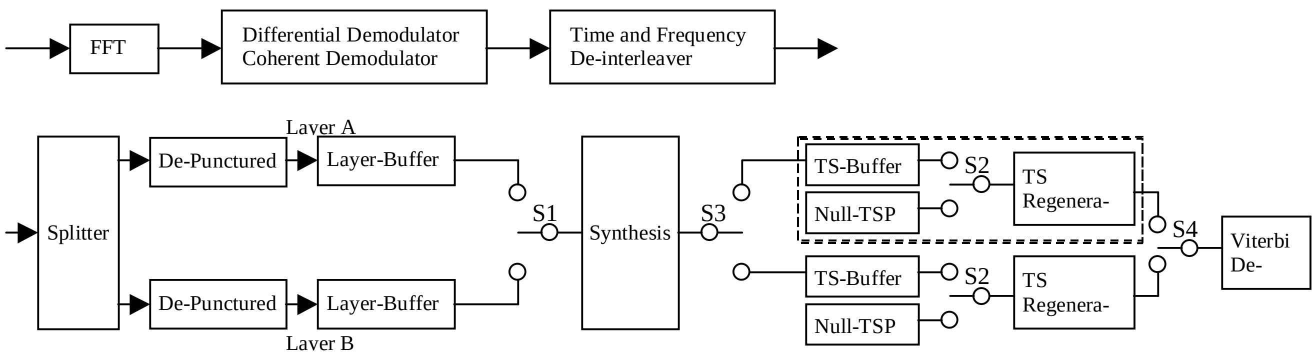


Fig. 7-2 Model receiver for Multiplex Frame pattern

7.2.1 Input stream to splitter

After the demodulation and de-interleaving processes, the signal is input to the splitter in order of segment number and carrier number (from low to high frequency, except for pilots) within a segment. It should be noted that delay compensation between the processing time of differential demodulation and that of coherent demodulation is necessary in the demodulation block.

An example of the order of segment data flow to the splitter is shown in figure 7-3. In this case, time is counted by the FFT sampling clock. The transmission parameters are shown in figure7-1.

Table 7-1 Example of hierarchical parameter set in 3-segment transmission

Mode		1
Guard Interval Ratio		1/8
Hierarchy 2	Layer A Layer B	DQPSK, Coding Rate = 1/2, 1 segment used 16QAM, Coding Rate = 3/4, 2 segments used

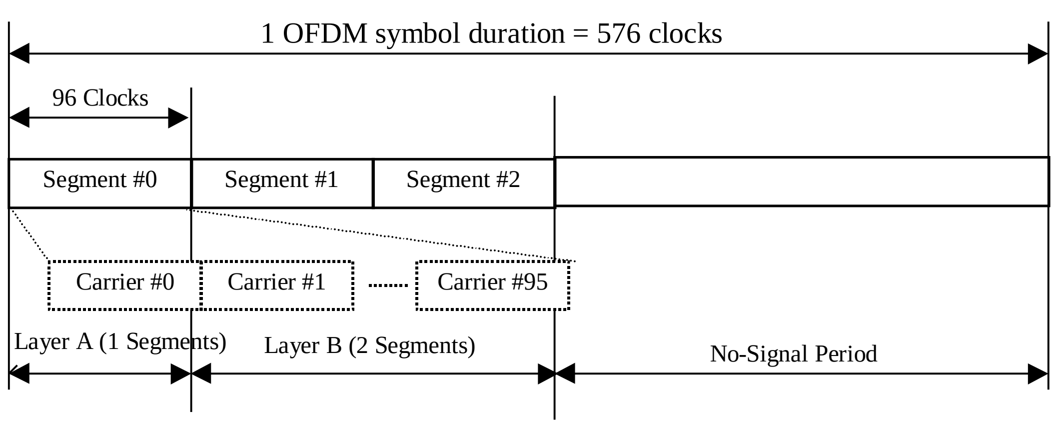


Fig. 7-3 Example of input stream to splitter in 3-segmennt transmission

In an OFDM-symbol duration, the data of 96 (=96useful × 1segment) carriers are input to layer A, then the data of 192 (=96 × 2) carriers are input to the B layer's position, and finally the no-signal period equivalent to 288 carriers follows. Here, the no-signal period corresponds to the sum of the guard interval and processing time for pilot carriers and remaining samples of 512-FFT sampling. This multiplex frame pattern repeats 204 times in an OFDM frame.

7.2.2 Operation of splitter to Viterbi Decoder

Data split into each layer are de-punctured and stored in each layer's buffer. It is assumed that the processing times are the same for each layer and zero in the model receiver.

When the k-th symbol data in one multiplex frame are input to the de-punctured block of layer X, the number of bits $B_{x,k}$ being stored in the buffer of layer X is as follows.

$$B_{X,k} = 2 \times ([k \times S_X \times R_X] - [(k-1) \times S_X \times R_X])$$

Where, *[ ]* denotes the calculation of rounded-down decimals, Rx denotes the coding the rate of the X layer's convolutional code, and S_x depends on the modulation scheme as shown in table 7-1.

Table 7-1 Values of S_x

Modulation	S_x
DQPSK/QPSK	2
16QAM	4
64QAM	6

When one packet's data of 408 bytes are stored in a hierarchy buffer, switch S1 is active and the data are transferred to a TS buffer. This transfer is assumed to be instantaneous.

The TS regeneration block looks up a TS buffer every TS packet period of 408 clocks, whether or not more than one packet's are stored. When more than one packet's data are stored, switch S2 is connected to the buffer and one packet's data are read out. And when no data are stored in the TS buffer, S2 is connected to null RS-TSP, and a null packet is read out.

Switch S3 switches the TS regeneration block to which the data are transferred from the layer synthesis block at the head of the OFDM frame (in the case of Mode 1). Following switch S3, switch S4 switches the TS regeneration block that delivers the data to the Viterbi decoder at three packet-periods (408 x 3 clocks) later to the change of S3.

For Mode 2, the switching period of switches S3 and S4 is half an OFDM frame (102 OFDM symbols), and for Mode 3, it is a quarter of an OFDM frame (51 OFDM symbols).

8. Signal format in connected transmission

8.1 Connected transmission

Concatenated transmission is defined as a transmission of multiple segments (i.e. multiple programs) from the same transmitter with no guard band.

An example of concatenated transmission for three TS's (TS1, TS2, and TS3) is shown in Fig. 8-1. Each TS signal is independently channel-coded as shown figure 2-1. After OFDM-frame adaptation, all segments symbol data are adapted for OFDM-signal generation by single IFFT.

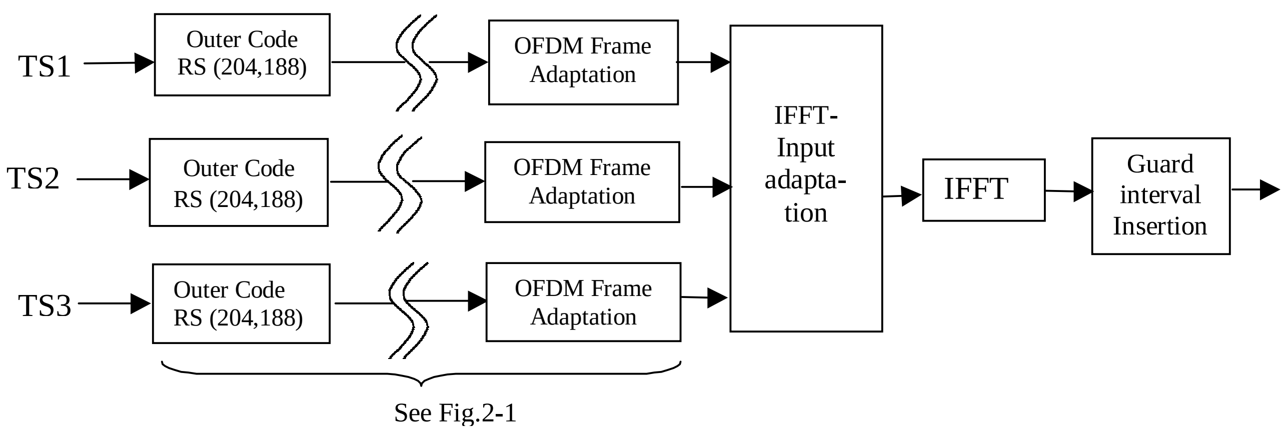


Fig. 8-1 Example of concatenated transmission (three TS's)

8.2 CP carrier in connected transmission

In an ordinary transmission, one CP carrier is added to the upper end of the band as shown in Fig. 8-2. This additional CP carrier is used as a reference signal for the coherent demodulation.

In concatenated transmission, on the other hand, the first carrier of the upper adjacent segment can be treated as a CP of the desired segment. Accordingly, only one CP is enough for the connected transmission as shown in figure 8-3.

Fig. 4-2 CP-carrier in an ordinary transmission

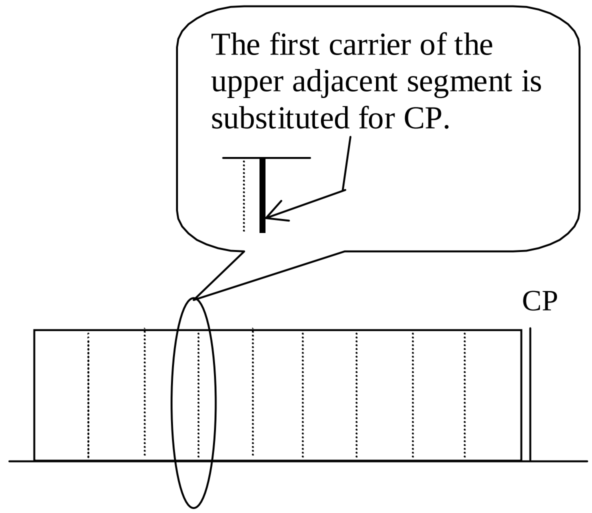


Fig. 8-3 CP-carrier in connected transmission

8.3 Phase compensation for connected transmission

8.3.1 Pre-compensation for segment signal

Phases of all symbol data of a segment are rotated by an amount before OFDM-signal generation. The amount of phase compensation is determined as a product of a frequency difference (fr-ft) and a guard interval.

ϕ = (fr-ft) x Tg(guard interval)

where, ft is a frequency of connected transmission, and fr is a centre frequency of desired segment(s).

Frequency difference (fr-ft) is normalised in terms of number of segments. Amounts of phase-rotation ϕ are shown corresponding to frequency differences counted segment in table 4-1.

Table 4-1 Phase compensation ϕ for each symbol of a segment (x 2π)

Mode	GIR	Difference of centre frequencies (fr-ft) counted by segment														
		-n	-6	-5	-4	-3	-2	-1	0	-1	-2	-3	-4	-5	-6	+n
1	1/32	-mod(3n,8) /8	-2/8	-7/8	-4/8	-1/8	-6/8	-3/8	0	3/8	6/8	1/8	4/8	7/8	2/8	mod(3n,8) /8
	1/16	-mod(3n,4) /4	-2/4	-3/4	0	-1/4	-2/4	-3/4	0	3/4	2/4	1/4	0	3/4	2/4	mod(3n,4) /4
	1/8	-mod(n,2) /2	0	-1/2	0	-1/2	0	-1/2	0	1/2	0	1/2	0	1/2	0	mod(n,2) /2
	1/4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1/32	-mod(3n,4) /4	-2/4	-3/4	0	-1/4	-2/4	-3/4	0	3/4	2/4	1/4	0	3/4	2/4	mod(3n,4) /4
	1/16	-mod(n,2) /2	0	-1/2	0	-1/2	0	-1/2	0	1/2	0	1/2	0	1/2	0	mod(n,2) /2
	1/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1/4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/32	-mod(n,2) /2	0	-1/2	0	-1/2	0	-1/2	0	1/2	0	1/2	0	1/2	0	mod(n,2) /2
	1/16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1/4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

“Mod(i,j)” indicates the remainder of dividing i by j.

GIR: Guard Interval Ratio

The phase rotation amounts to 2nπ every 8-symbol period. Accordingly, at the first symbol of a frame in which the synchronisation word of TMCC is W_0, the amount of phase rotation is prescribed as 0.

8.3.2 Phase rotation in reception

When desired segment(s) uses the first carrier of the upper adjacent segment as a reference signal, the phase of that carrier should be rotated every symbol in accordance with table 8-2.

Table 8-2 Phase rotation Δϕ for the first carrier of the upper adjacent segment (x 2π)

Condition of desired segment	Guard interval ratio	Condition of upper adjacent segment: 1-segment transmission	Condition of upper adjacent segment: 3-segment transmission
1	1/32	-3/8 (1), -3/4(2), -1/2(39)	-6/8, -2/4, 0
	1/16	-3/4, -1/2, 0	-2/4, 0, 0
	1/8	-1/2 , 0, 0	0, 0, 0
	1/4	0 , 0 , 0	0, 0, 0
3	1/32	-6/8, -2/4, 0	-1/8, -1/4, -1/2
	1/16	-2/4, 0 , 0	-1/4, -1/2, 0
	1/8	0, 0 , 0	-1/2, 0, 0
	1/4	0, 0 , 0	0, 0, 0

(1),(2) and (3) indicate transmission mode.

8.4 Parameter restrictions in connected transmission

(1) The same mode should be applied for all segments.

(2) The same guard interval length must be used for segments.

Because all OFDM symbols in connected transmission should be synchronised with each other, modes having different symbol lengths cannot be mixed.

(3) OFDM-signal generation must be carried out by single IFFT operation.

The frequencies of all segments must be completely synchronised. For this reason, it is necessary in practice that single IFFT is used for signal generation (size increases with increase in number of carriers).

Recommended IFFT sizes are given with respect to total number of segments in able 4-3.

Table 8-3 Number of segments and IFFT sizes

Mode		Number of segments													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Number of carrier	109	217	325	433	541	649	757	865	973	1081	1189	1297	1405	1513
	IFFT size	256	512		1024			2048							
	IFFT order	8	9		10			11							
2	Number of carrier	217	433	649	865	1081	1297	1513	1729	1945	2161	2377	2593	2809	3025
	IFFT size	512	1024		2048			4096							
	IFFT order	9	10		11			12							
3	Number of carrier	433	865	1297	1728	2161	2593	3025	3457	3889	4321	4753	5185	5617	6049
	IFFT size	1024	2048		4096			8192							
	IFFT order	10	11		12			13							